NORTHUMBERLAND
STRAIT
CROSSING PHASE I

NORTHUMBERLAND STRAIT CROSSING
PASSAGE DU DÉTROIT DE NORTHUMBERLAND

1964 PHASE 1 REPORT - RAPPORT DE LA PHASE 1

TO GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS

AU GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS

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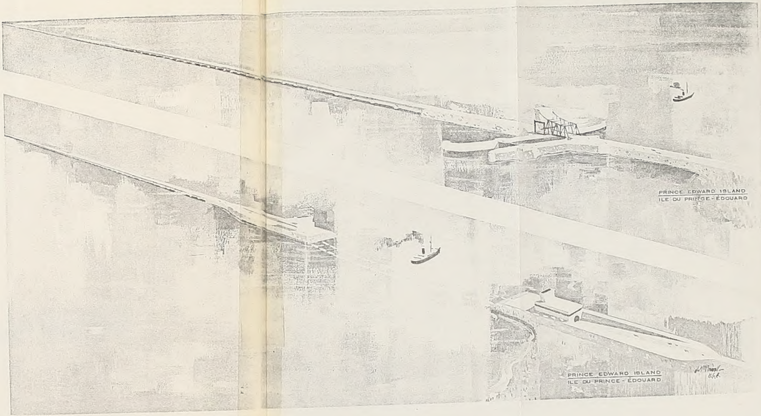

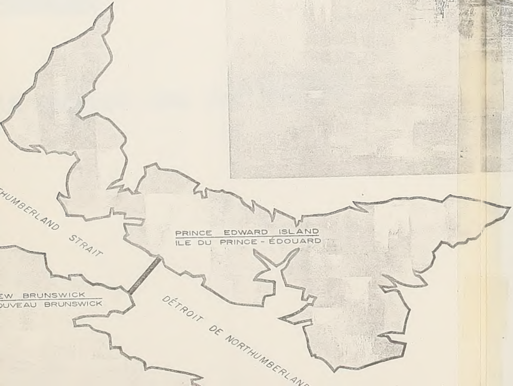

NORTHUMBERLAND STRAIT CROSSING
PASSAGE DU DÉTROIT DE NORTHUMBERLAND

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SUMMARY

The Phase I engineering studies of the Northumberland Strait Crossing cover all field and office investigations required for the preparation of preliminary designs and cost estimates for all alternative types of crossing which, on the basis of these studies, appear to be economical and practicable. The types of crossing which were considered in detail, either individually or in combination, are:

(a) — Rockfill Causeway
(b) — Bridge
(c) — Prefabricated Tunnel
(d) — Tunnel Driven in Rock

During the early stages of the investigation, it became evident that a crossing having the minimum effect on existing conditions in the Strait would be desirable, provided that it could be designed to withstand the effects of extreme storms and the ice action in the Strait, and remain competitive with a complete rockfill causeway similar to the type which was built across the Canso Strait.

Up-to-date estimates showed that the cost of remedial works that would be required due to changes in tidal regime and increased storm surges following construction of the complete rockfill causeway, would total approximately $23 million. In addition, division of the Strait into two bays could have adverse effects on fisheries. If a clear flow area, equal to about 35 per cent of that originally available, were provided by openings in the crossing, the crossing would have virtually no effect on tides and storm surges.

The bridge proposal presented in the report appears to be an economical means of providing the desirable flow area. A design of prefabricated pier has been evolved which can be rendered stable against wave action and heavy ice thrusts, and which eliminates the cost and hazard associated with in situ construction of piers in the Strait. The proposed bridge pier is similar to the recently constructed prefabricated foundation for the Prince Shoal lighthouse. Sufficient clearance is provided under the bridge for the passage of lobster boats and small craft.

If provision for uninterrupted flow of all marine and vehicular traffic is required, this can be most economically accomplished by placing a short section of prefabricated tunnel in the Strait on the Prince Edward Island side of the crossing. A depth of 32 feet at low water would be provided in a navigation channel over the tunnel.

Offering a substantial saving in cost, but not providing for the uninterrupted flow of all traffic, is a navigation lock. Vehicular traffic would cross the lock via an opening bridge. Preliminary studies indicate that the volume of shipping through the Strait is at present light, and that opening of the span will not interrupt vehicular traffic more than twice a day. The navigation lock would provide the same general clearance as that employed in the St. Lawrence Seaway.

As a further alternative to a rockfill causeway, bridge and prefabricated tunnel crossings, a preliminary study was made of a tunnel driven in rock under the Strait. This tunnel, approximately eight miles long, poses problems in ventilation that would limit its capacity to handle peak volumes of road traffic. The estimated cost of the ventilating machinery is of the order of $20 million. The high cost of constructing and later ventilating and maintaining the long tunnel crossing makes this alternative unattractive.

Preliminary studies of road traffic to the Island have indicated that serious consideration should be given to providing facilities that would economically allow, by initial provision or later conversion, four lanes of vehicular traffic to pass over the crossing possibly within 25 years after its construction. The provision of these facilities is examined for all types of crossing studied.

Cost estimates of the various crossings studied are given in Table 4 on Page 45. This table shows that the minimum overall expenditures are associated with Schemes 2 and 3, both of which incorporate a section of bridge carried on prefabricated piers. Scheme 2 provides a prefabricated tunnel section under a navigation channel to allow the uninterrupted flow of all traffic; Scheme 3 a navigation lock and opening bridge. The following summary table gives the estimated costs of Schemes 2 and 3, with provision for various vehicular traffic requirements.

Vehicular Traffic Requirement	Scheme 2 Crossing with Prefabricated Tunnel Section	Scheme 3 Crossing with Navigation Lock & Opening Bridge
A — Highway and Rail	$146 million	$119 million
Highway only		
B — Two-lane	98	87
C — Four-lane	109	99
D — Two-lane (28-ft pavement)	—	84
E — Two lanes convertible to four lanes	—	88
Cost of conversion	—	17

The table indicates that —

(a) Provision of a prefabricated tunnel section in the crossing to ensure the uninterrupted flow of traffic entails an additional expenditure of at least $10 million.

(b) Provision of rail facilities in addition to a two-lane highway crossing involves the additional expenditure of at least $27 million. Comparison of the cost of a crossing for highway and railway with that for a four-lane highway, indicates a difference of at least $20 million.

(c) The minimum cost of a crossing with two-lane highway only is $84 million.

(d) The cost of providing in (c) the additional width of causeway and the pier caps required for later converting the two-lane highway to four lanes is $4 million; the future cost to provide four lanes for traffic on this crossing would be $17 million.

It is recommended that Phase II engineering studies should further develop the design of a crossing having the minimum effect on existing conditions in the Strait, and with facilities for passage of all foreseeable traffic. To this end, the following specific studies are required:

(i) The further development of a bridge section of crossing on prefabricated piers.

(ii) The further design of rockfill sections of crossing common to all schemes, and continued investigation into the sources of construction materials.

(iii) The observations and measurement of ice action in the Strait, and the study of future ice behaviour in the vicinity of the crossing through tests on hydraulic models.

(iv) The extension of preliminary studies on vehicular and marine traffic to the degree required to determine with confidence the facilities that should be provided for road, rail and marine traffic.

It is also recommended that geological investigations be continued in the area of the navigation lock.

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MARS 1964 | PLANCHE I

NORTHUMBERLAND STRAIT CROSSING

GENERAL AREA MAP

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MARCH 1964 | PLATE I

NORTHUMBERLAND STRAIT CROSSING

PHASE I REPORT

Part I — General

INTRODUCTION

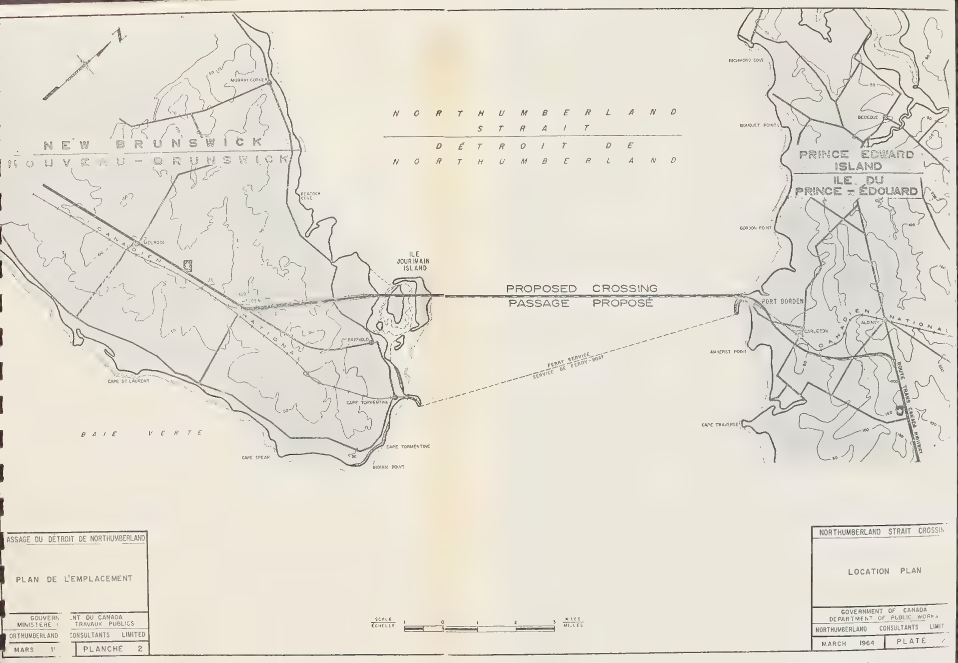
Purpose

This report summarizes the results of studies comprising a comprehensive feasibility and cost analysis of the various practicable methods of constructing a permenent crossing of the Northumberland Strait between Prince Edward Island and New Brunswick. The studies were carried out by Northumberland Consultants Limited in conjunction with various Government agencies, principally the Department of Public Works.

Description of Site

Prince Edward Island lies in the southern part of the Gulf of St. Lawrence, separated from the mainland of New Brunswick and Nova Scotia by the Northumberland Strait. A map of the general area is presented on Plate 1. The Strait is about two hundred miles in length, and varies in width from 25 miles, to 8 miles at its narrowest point between Port Borden and Cape Tormentine. The line of the proposed crossing is between Jourimain Island and Borden as shown on Plate 2. On this line the depth of water reaches about 95 feet and averages approximately 60 feet. The average depth of water in the Strait varies from 80 feet in the east to 150 feet in the northwest.

The climate of the area is temperate, making Prince Edward Island attractive as a summer resort with its many miles of sandy beaches and comparatively warm weather. In the winter months, however, the area is subject to fairly frequent storms accompanied by winds with gust speeds up to 60 or 70 miles an hour. The mean January daily minimum temperature is approximately 10 degrees F while the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MELROSE
BAYFIELD
CANADIEN NATIONAL
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CAPE TORMENTINE
CAPE TORMENTINE
CAPE SPEAR
INDIAN POINT
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RICHMOND COVE
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PORT BORDEN
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MARCH 1964
PLATE

mean July daily maximum temperature is about 75 degrees F. The prevailing wind direction in the winter is westerly.

Ice conditions in the Strait during the winter vary widely from year to year depending upon climatic conditions. Normally a completely closed ice cover does not form in the Strait as the centre ice is constantly in motion. During the months of February and March, the Strait between Borden and Cape Tormentine is often covered entirely by landfast and drifting ice. Ice rafts move up and down the Strait under the action of wind and tides. The ice is by no means entirely of local origin, much of it drifting southward from ice sheets formed along the shores of the Gulf of St. Lawrence.

The New Brunswick and Nova Scotia coastlines of the Strait are irregular and generally fairly low lying, the cliffs and rock outcrops seldom attaining a height of more than 25 feet. The rocks of the area are mainly carboniferous sandstones and shales, the overlying soil being, in general, thin. Population along the coastline is mainly centred in and around small fishing villages and a few towns. The economy of the area is based mainly on agriculture and fishing.

On the Prince Edward Island side of the Strait the coastline is indented by three major bays, Egmont, Bedeque and Hillsborough. Here again, the land is comparatively low lying. The coastal area is generally fertile agricultural land which is extensively farmed. Another basic industry is fishing, while tourism has, in recent years, been playing an increasingly important role in the island's economy.

History and Present Status of Transportation Facilities

From the time of the early settlers until the year 1832, transportation to the Island was maintained by sailing vessels calling at various ports. In 1832, the first regularly scheduled steamer service was begun between Pictou, Nova Scotia, and Charlottetown, Prince Edward Island.

In 1852, a similar service was initiated between points in Prince Edward Island, New Brunswick, and Nova Scotia. The vessels attempted to contend with winter ice but with little or no success, until the advent of the big ice-breaking car ferries in 1917 when the S.S. "Prince Edward Island" inaugurated the Cape Tormentine - Port Borden C.N.R. service.

Winter transportation to and from the mainland prior to 1915 had been almost entirely by way of ice boats. These were specially built boats which were rowed through the open water sections then towed by the crew and passengers on reaching solid ice.

The service inaugurated by the S.S. "Prince Edward Island" was supplemented in 1931 by the M.V. "Charlottetown". The "Charlottetown" continued in service until 1941 and the M.V. "Abegweit" was put in operation in 1948.

In 1962, the M.V. "Confederation" was added to the service but it was not constructed for operation during the ice season. In 1963, it was announced that a new and larger icebreaker was being ordered, and it was hoped to have her in service in two to three years. With all three of the present vessels working to capacity, and supplemented by the S.S. "Scotia II" which carries rail cars only, there are many periods during the summer tourist season when motorists are forced to wait many hours for a crossing. A survey made of traffic in the period between May 1 and September 15, 1959, for example, showed that many vehicles missed one crossing and some vehicles missed two crossings of the ferry due to overloading of the service. In 1963 more than 214,000 vehicles were carried on the Port Borden to Cape Tormentine service.

By the time the new ferry is in service, the S.S. "Prince Edward Island" will be ready for retirement and, with traffic volumes increasing at a rate of over 7 per cent annually, it would appear that the overloading during the summer months will become increasingly acute.

In addition to the C.N.R. operated Borden-Tormentine rail and car service, a car-ferry service operates during the open navigation season between Wood Island, Prince Edward Island, and Caribou, Nova Scotia. This service carried approximately 70,000 vehicles during 1963 and, as at Borden-Tormentine, there were often long waiting periods for motorists during busy periods. Both of these ferry services are subsidized.

History of Investigation

Over seventy years ago, a permanent link to the island from the mainland was considered. A British consulting engineer, Sir Douglas Fox, was retained in 1891 to investigate the feasibility of an underground railway tunnel. He advised that such a crossing was feasible if constructed between Money Point in New Brunswick and Carleton Point, Prince Edward Island, close to the present ferry route between Borden and Cape Tormentine. He estimated that a brick-lined tunnel with a circular section 18 feet in diameter would cost approximately $12 million and take about six years to construct.

In 1955, the Canso Causeway, between Cape Breton Island and mainland Nova Scotia, was successfully completed and the possibility of a similar structure to connect Prince Edward Island with the mainland began to receive active consideration.

In 1956, the Provincial Government of Prince Edward Island approached the Federal Government with a proposal to investigate the feasibility of a crossing and, in that year, the Department of Public Works made some preliminary field investigations of construction materials in the area. It became apparent that a far more detailed investigation was required to assess the feasibility and cost of a crossing, and this was undertaken by the Department and several government agencies with the assistance of consulting engineers. The conclusions confirmed that a permanent crossing is feasible.

In 1962, a group of consulting engineers, Northumberland Consultants Limited, was retained to carry out a comprehensive study of the proposed crossing, including a detailed review and correlation of all previous investigations.

Terms of Reference and Scope of Work

In the agreement between the Department of Public Works and Northumberland Consultants Limited, the work of the consultants is divided into four distinct phases, designated Phases I to IV, to be carried out in sequence but with the provision that the work can be terminated upon the completion of any phase. As each phase is completed, the consultant is required to prepare and submit a comprehensive report incorporating recommendations for work to be undertaken in the succeeding phase.

Phases I and II cover studies and preliminary engineering to culminate, at the end of Phase II, in a definite selection of the type and principal features of the crossing. Phase III comprises the preparation of detailed designs, specifications and drawings for construction, and the final phase the complete supervision and inspection during construction.

The detailed terms of reference for Phase I, summarized in this report, are essentially as follows:

1. Execution of all preliminary studies, surveys and investigations necessary for the preparation of a comprehensive report of all economically feasible possibilities for the project.
2. A review of all existing reports and data concerning the project.
3. Performance of all sounding and boring surveys at the proposed site of the project necessary for the execution of the Phase I studies.
4. The submission of preliminary designs and cost estimates for all the alternative types of crossings which, on the basis of the Phase I studies, appeared to be practical and economically feasible.

In order to carry out this work, it has been necessary to investigate the many factors which influence the economics of constructing the crossing. The studies have included the investigation of the geological structure underlying the Strait, ice formation and tidal action in the Strait, topographic surveys of the land approaches, investigations of the feasibility and approximate costs of construction materials, and an appraisal of present road, rail, and marine traffic and the probable future trends in such traffic. The work has also included an analysis of the effects of changes in the tidal regime due to the influence of a barrier or a restriction in the Strait on existing highways, harbour facilities, coastal lands, and communities along both shorelines.

DESIGN CONSIDERATIONS

A crossing of the Northumberland Strait will affect tidal levels and currents throughout the Strait, and the magnitude of storm surge that may be experienced after its construction. A rockfill causeway, completely closing the Strait, will require the execution of extensive remedial measures and might also affect fish stock. The exposed location of the crossing makes it susceptible to attack by waves during the open water season, and by ice action in winter. All these factors were considered in the course of preparing alternative designs. Present and future volumes of road and rail traffic to the Island and the size and number of ships using the Strait were other design considerations.

Hydraulic Aspects

Tidal Levels and Currents — The variation of tidal levels along our coasts is caused by ocean tidal waves which rise and fall in response to astronomical tide-raising forces. The tidal wave that originates in the Atlantic enters the Gulf of St. Lawrence through the Cabot Strait and, near the Gaspe coast, branches northwards to the St. Lawrence River and southwards towards Prince Edward Island. Its path from Cabot Strait to the eastern end of the Northumberland Strait is greater than that to the western end, and consequently the wave arrives five hours later at the eastern end. The time difference between waves entering opposite ends of the Strait results in (a) maximum tidal range being experienced at Canoe Cove where the opposing waves meet, and (b) substantially zero tide level fluctuations being experienced in the Strait at an amphidromic point located in the narrows near West Point, Prince Edward Island.

Construction of a crossing at the narrows between Cape Tormentine and Borden in Northumberland Strait will, if it obstructs tidal currents through the Strait, affect tidal levels throughout its length. Increase in high tide level would cause flooding in certain areas, whilst decrease in low tide level in some harbours would entail additional dredging. Changes in tidal currents would also affect the rate of coastal erosion and the movement of drifting ice.

The greatest change in tidal conditions will occur with the construction of a rockfill crossing completely blocking the narrows. Provision of bridge or tunnel sections will provide openings for tidal flows and thus reduce the crossing's effect on tidal conditions. Table I, below, gives tidal ranges to the east and west of a crossing, and the maximum currents at the crossing that arise during a fairly extreme spring tide before and after construction. Where openings have been left in the crossing, their extent is represented in Table I as a percentage of the original cross sectional area of the Tormentine-Borden narrows.

TABLE I

Tidal Ranges and Maximum Currents at Site of Crossing

	East Side		West Side		Current
	Change in Tidal Range (feet)	Tidal Range (feet)	Change in Tidal Range (feet)	Tidal Range (feet)	Maximum Through Opening (knots)
Existing Conditions	0	7.5	0	7.5	2.3
Complete Closure	+5.5	13.0	+2.5	10.0	—
10% Opening	+2.9	10.4	—2.0	5.5	11.2
25% Opening	+0.9	8.4	—1.8	5.7	7.7
35% Opening	+0.1	7.6	—0.8	6.3	5.9

Table I shows that complete closure of the narrows by a rockfill crossing increases the tidal range on the east side of the crossing by 5.5 feet, and on the west side by 2.5 feet. Bridge or tunnel sections in the crossing, providing openings totalling 35 per cent of the cross section area of the narrows, reduces the changes in the tidal range to less than 0.8 feet. The maximum current through the openings will be 5.9 knots during extreme spring tide and less than 4 knots during an average tide.

As the calculated tidal levels and maximum currents at the narrows do not give in detail a picture of changes in tidal levels and currents after construction of a crossing, a model is being constructed at Coldbrook, Saint John, New Brunswick, to examine the tidal regime at harbours and other key points along the Strait and to verify the tidal calculations.

Storm Surges — Storm surges are large fluctuations in sea level generated by gale force winds and associated changes in barometric pressure. The storm surge in the North Sea and English Channel in 1953 had a height of 10 feet and, in Britain, flooded 160,000 acres of land with subsequent cost of repairs amounting to $21 million. Other areas in Belgium, Holland and Germany were affected to a similar extent. The orientation of Cabot Strait and the Strait of Belle Isle is not so conducive to the generation of storm surges as that of the North Sea and English Channel. An examination of 50 years of tide gauge records at Charlottetown indicated that the maximum storm surge experienced was 4.3 feet. Since this surge occurred with a low state of tide it did not result in an exceptionally high water level.

Division of the Strait into two large bays by construction of a rock-fill crossing without openings will, by entrapping the surge flow, increase the height of storm surges in either half. To evaluate the possible increase in storm surge height, an examination was made of hydraulic and hydrometeorological conditions during the storm of January 20/21, 1961. This storm gave rise to the highest recorded water level in Charlottetown which was 7.6 feet CGD. The study indicated that should a similar storm occur after construction of a rock-fill crossing without openings the maximum still water levels at Summerside and on the west side of the causeway will be raised 3.8 feet above the highest levels yet experienced. If a similar storm were to occur further east, as did that of January 11, 1952, water levels on the east side of the causeway would rise 3.6 feet higher than the maximum water level which has been recorded at Borden. At Charlottetown, the increase over the highest recorded level will be 2.3 feet.

Provision of an opening in a crossing, equal to or greater than 35 per cent of the original cross section of the Tormentine/Borden narrows, will essentially eliminate any increase in maximum water level due to storm surges.

Wind Set-up — The force of the wind blowing over the water surface moves surface layers towards the lee shore, thus raising the level at that location. This rise in water

level is called wind set-up. If the Strait is divided by a rockfill crossing into two large bays, each will be subject to wind set-up. The western half of the Strait would be affected by the north northwestern winds, while the eastern section would be affected by the east southeastern winds. Analysis of wind data from the Summerside meteorological station on Prince Edward Island for the period 1950-1962 was undertaken by the Department of Transport to obtain frequency duration data on wind direction, speed and duration. The wind set-up was calculated using procedures laid down by the U.S. Corps of Engineers in their Technical Report No. 4, 1961. Results of these calculations are given in Table 2.

TABLE 2

Wind Set-up at Full Causeway — Period 1950 — 1962

Wind Velocity mph	East-Southeast Number of Storms Exceeding V	East-Southeast Wind Set-up (feet)	West-Northwest Number of Storms Exceeding V	West-Northwest Wind Set-up (feet)
30	20	1.3	172	0.9
40	7	2.4	14	1.7
50	1	3.8	—	2.7

The above table shows that had a complete rockfill crossing been constructed prior to 1950, a maximum wind set-up of about 3.8 feet would have been experienced once on its east side. The table also shows that a wind set-up of about 2 feet will occur relatively frequently. These conditions could increase the frequency of flooding near the causeway. As with storm surges, however, the maximum set-up is not necessarily associated with high astronomical tide.

Wind-Generated Waves — In view of the exposed site of the Northumberland Strait Crossing, a careful study of its protection against wind-generated waves is necessary. On the west, the crossing is unprotected against west-northwest winds for a distance of 50 miles, and to the east against east-southeast winds for a distance of some 60 miles. As there are no long-term records of wave heights at the proposed site of the crossing, the wind speeds recorded at Summerside were used to determine wave heights at the crossing. Wave heights were calculated using the commonly accepted formula of Bretschneider, Sverdrup and Munk, which relates the height and period of the characteristic or significant wave to wind speed and wave fetch. The results of these computations are shown on Table 3.

TABLE 3

Characteristic Wave Height during Storms at Full Causeway Period 1950 — 1962

Storm Class V mph	East-Southeast		West-Northwest	
	Number of Storms	Characteristic Wave Height	Number of Storms	Characteristic Wave Height
30-40	13	7.3	158	6.5
40-50	6	10.2	14	9.2
50-60	1	12.4	—	10.9

The height of the characteristic wave is the average of the highest third of the waves in a wave group or train, and corresponds approximately with the height that is judged by eye. The frequency of occurrence of waves higher than the characteristic wave is approximately 12 per cent. The highest wave in a group can be 60 per cent higher than the characteristic wave.

Overtopping of Rockfill Crossing by Wind-Generated Waves — Design studies indicate it to be uneconomic to completely prevent overtopping of a rockfill causeway by waves during a repetition of the most severe storms so far experienced. In order to minimize damage to the road bed and to reduce the frequency of delays to road traffic due to spray during storms, the crest elevation was established on the basis that no more than ten waves per year on the average should overtop the causeway. These extreme waves will have heights between 17 and 20 feet. Studies of the waves that would have been generated by storms recorded between 1950 and 1962 indicated that a rockfill causeway would have been closed for two to three hours near high water for each of the 21 most severe storms in that 12-year period because of the risk of overtopping. To prevent overtopping an additional 4 feet will be required on the recommended height of the rockfill sections.

Armour Protection Against Wave Action — With the causeway's exposed position, it may not be economical to provide armour stone large enough to avoid some displacement by waves during the maximum storm of record. Studies based on the calculated wave heights given in Table 3 indicate that for optimum economy in construction and maintenance, the weight of armour stone should be between 6 and 9 tons.

A wave-measuring station is now in operation at the site of the proposed Northumberland Strait Crossing. When sufficient data is obtained from this, it will be possible to find by model studies the most suitable wave protection to the slopes of rockfill sections and the shape of bridge piers to minimize spray on the roadway of a bridge crossing.

Ice Action

The severe ice conditions in the Northumberland Strait during the months of February, March, and early April considerably influence the design of the crossing. The report dated 1958 on sea ice conditions in the Northumberland Strait area, by Dr. C.N. Forward of the Geological Branch of the Department of Mines and Technical Surveys of Canada, indicates that the Strait is at present never covered by a closed ice sheet, as tidal currents and wind tend to keep the centre ice constantly in motion.

Near the shores, a continuous sheet of landfast ice begins to form in late December and grows seaward during January and February, attaining a width varying from a few yards on exposed headlands to several miles in shallow bays and harbours.

In January, pack ice of local origin begins to form offshore and attains a thickness of about three feet. The floes of pack ice vary greatly in size and, although many are only a few feet in diameter, others of 500 feet in diameter are quite common and occasionally floes of about three miles in diameter are encountered. These floes are kept in constant motion by the action of tides and winds. In late February and March, between 80 and 100 per cent of the area between the strips of landfast ice is covered by ice floes. Pools and leads appear frequently between the ice floes as wind and tide redistribute the pack.

During late February and March, conditions are made worse by the appearance of relatively thick floes of winter ice which have been identified as originating in the central part of the Gulf of St. Lawrence. The constant motion of the ice gives rise to considerable ridging, and the rafting of one floe on another greatly increases the thickness of the ice pack.

After completion of the crossing, it is expected that a strip of landfast ice will form along the rockfill section. This strip will minimize the incidence of freezing spray on the crossing and provide protection to the armour stone against the action of moving ice floes. The strip, however, will itself be exposed to heavy pressure due to the influence of strong winds and tides, so that ice may be piled up the slope of the causeway. Piling up of ice along the shores of the Northumberland Strait was observed by Mr. W. A. Black of the Geographic Branch, Department of Mines and Technical Surveys of Canada, and noted in his paper "Gulf of St. Lawrence Ice Survey, Winter 1961". Measures to prevent this phenomenon interrupting traffic will be studied.

Ice loads against the piers of a bridge crossing can occur as follows:

(a) - By the impact of a drifting ice floe on collision with the pier.

(b) - By the shifting, due to wind or current, of ice packed around a pier or series of piers.

(c) - By an ice jam blocking the openings between a number of piers, so that the hydrostatic pressure due to tidal differences across the causeway is transferred onto the piers.

For the preliminary design studies undertaken under Phase I of the Northumberland Strait Crossing investigation, the ice loads due to impact of ice floes and the shifting of packed ice were assumed to act normal to the bridge pier surface, and to be equal to the crushing strength of ice multiplied by the width of the pier and the ice thickness.

The crushing strength of ice varies greatly with its history and with temperature. For the preliminary studies undertaken in Phase I, the crushing strength was assumed to average 400 psi. This value of crushing strength is in accordance with safe engineering practice. As an additional precaution, the pier faces were sloped in a manner that would tend to split the ice floes before the full crushing strength was attained.

The thickness of ice floes in the Strait has not been measured with precision. Dr. Forward, in his 1958 report, indicates that ice periodically grounds on the Jourimain Shoal in water approximately 12 feet deep, and Dr. Black observed, during the winter of 1961, that "in the ice-congested areas of Northumberland Strait, where tidal action was effective as a builder of pressure ridges, the sea ice was over 20 feet thick". These depths and thicknesses do not, however, represent the thickness of solid ice, but rather the accumulated depth of over-lapping layers intermixed with air pockets and crushed ice. For the purpose of calculating the ice thrust on bridge piers in the Strait, the thickness of ice floes was taken to be the equivalent of 15 feet. The value chosen is conservative and in excess of the thickness normally used in bridge pier design.

The load transferred onto bridge piers by blockage of the bridge opening by an ice jam was, for design purposes, taken as a hydrostatic pressure of 10 feet acting on the entire area of the water passage between piers. The hydrostatic pressure of 10 feet represents the maximum difference between tidal levels on the east and west sides of the crossing on complete closure of the narrows.

Measurements are being taken this winter of the thickness and strength of ice floes in the Strait, and of ice forces on the pier at Bor-

den. Model tests will be conducted to investigate the danger of ice jamming the openings between the bridge piers.

Cost of Damages and Remedial Measures

Construction of a rockfill causeway dividing the Northumberland Strait into two bays will result in marked changes in the tidal regime and increased storm surges. These changes could cause damage along the shores if extensive remedial works were not previously undertaken.

Estimates of the cost of the required remedial works were made in 1958 and 1959 by Federal and Provincial Government Departments. A detailed study was carried out by the Geological Branch of the Department of Mines and Technical Surveys of Canada to estimate the cost of flood damage to shoreline properties. The Harbours and Rivers Engineering Branch of the Department of Public Works of Canada made a survey and estimated the cost of increasing the height of docks and wharves in the area, and also estimated the increased costs for dredging. The Development Engineering Branch of the Department of Public Works of Canada made detailed estimates of the cost of raising highways and bridges in Nova Scotia and Prince Edward Island. The Department of Public Works (Highways Division) of New Brunswick made a similar study in that province.

The present study has indicated that storm surges will give rise to water levels approximately one and one-half feet higher than those on which the previous estimates were based. Also, in the interim period, many roads which were gravel in 1959 have been paved and the general value of lands and buildings has increased in some areas.

As a detailed re-evaluation of remedial costs would be very time-consuming and not economically justified as part of the Phase I study, it was decided to review the previous detailed estimates and amend these to allow for the calculated increase in high water level and changes in costs, and to undertake a limited field inspection to ascertain increases in shoreline usage.

The review and inspection were subdivided into an examination of -

(a) - Highways and associated structures.

(b) - Marine structures and harbours.

(c) - Erosion protection in built-up areas.

(d) - Coastal properties and adjacent buildings.

The present estimated costs of remedial measures are tabulated below, and show a total of approximately $23.2 million:

	Mainland	Prince Edward Island	Totals
Highways and Bridges	$ 7,740,000	$ 520,000	$ 8,260,000
Marine Structures and Dredging	$ 3,430,000	$2,490,000	$ 5,920,000
Erosion Protection — Built-up Areas	$ 3,300,000	$1,730,000	$ 5,030,000
Land Damages and Indemnity	$ 290,000	$ 320,000	$ 610,000
Building Damages and Indemnity	$ 2,260,000	$ 640,000	$ 2,900,000
Erosion Protection — General	$ 430,000	$ 50,000	$ 480,000
	$17,450,000	$5,750,000	$23,200,000

Fisheries

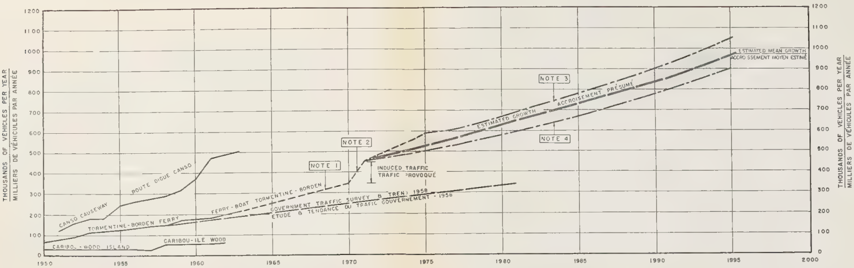
The Department of Fisheries, in a letter of January 25, 1963, indicated that if the Strait were divided into two bays by the construction of a complete rockfill causeway, the stocks of salmon, lobster and shellfish (oysters and clams) might be adversely affected. The few salmon, relative to the total average run, that do move through the Northumberland Strait to spawning grounds in Nova Scotia and New Brunswick, will be stopped by a complete blockage.

With division of the Strait into two bays, as would result with the adoption of a full causeway, warming of the waters will undoubtedly occur. Since summer water temperatures at the present time vary from 16 degrees C to 18 degrees C (60.8 degrees F to 64.4 degrees F), an increase of one or two degrees might bring the top temperature to a limit which is lethal for lobster. The Department of Fisheries' letter states that any warming in the surface water would probably eliminate the normal practice of holding these lobsters in pounds, traps or cars.

Should silting of the shellfish beds in the Strait occur during or after construction of a full causeway, this will be to their detriment or perhaps result in their extinction.

The Department of Fisheries' preliminary studies indicate that most of the crossing's adverse effects on fisheries would be eliminated by the adoption of a crossing incorporating a bridge section or other opening that allows a relatively free flow of water.

Before any scheme for crossing is adopted, the complete pattern of currents in the Strait, and the crossing's effect on the currents should be studied in the tidal model now at Saint John. The Department of Fisheries will then be able to assess, with accuracy, what changes the proposed scheme of crossing might have on fishing stocks.



NOTES

1 UNE AUGMENTATION DE 7% SERA MAINTENUE DE 1963 Á 1970 CELÁ EST LÉGÈREMENT INFÉRIEUR AU RÉGIME D'AUGMENTATION ACTUEL

2 UNE AUGMENTATION DE 30% SE PRODUIRA APRÈS LA CONSTRUCTION DU PASSAGE, À CAUSE DU TRAFIC PROVOQUÉ

3 ET 4 POUR LA PERIODE QUI SUIT LA CONSTRUCTION DU PASSAGE, DEUX ESTIMES SONT INDIQUÉS
3 - ASSUME UNE AUGMENTATION CONTINUE DE 7% JUSQU'EN 1975, PUIS UN ACCROISSEMENT ANNUEL DE 3%
4 - ASSUME UNE BAISSE IMMEDIATE JUSQU'A UN ACCROISSEMENT ANNUEL DE 3%
CES DEUX HYPOTHÈSES DONNENT UNE BANDE GRAPHIQUE DE TRAFIC PROBABLE, DE LAQUELLE L'ACCROISSEMENT MOYEN EST DÉRIVÉ

	FERRY RECORDS / STATISTIQUES DU FERRY-BOAT		ESTIMATED FUTURE TRAFFIC / TRAFIC FUTUR PRÉSUMÉ		
	1962	1963	1975	1985	1995
TOTAL ANNUAL TRAFFIC / TRAFIC ANNUEL TOTAL	199,275	214,000	525,000	725,000	975,000
A A D T (VEH / DAY) / M J T A (VÉH / JOUR)	545	586	1,440	1,990	2,670
TOTAL SUMMER TRAFFIC (JUNE 29 TO SEPT 2) / TRAFIC ESTIVAL TOTAL (DU 29 JUIN AU 2 SEPT)	87,667	97,931	262,000	362,000	585,000
% OF ANNUAL / % DU TRAFIC ANNUEL	44 %	45 6%	50 %	55 %	60 %
A S D T (VEH / DAY) / M J T E (VÉH / JOUR)	1,326	1,482	3,970	5,490	8,860
8 PEAK DAYS (VEH / DAY) / 8 JOURS DE POINTE (VÉH / JOUR)	1,625	,875	5,040	6,960	11,120
RATIO PEAK DAYS / A S D T / RAPPORT JOURS DE POINTE / M J T E	1 23	1 27	1 27	1 27	1 27
PROBABLE PEAK HOUR ON AVERAGE SUMMER DAY (VEH / HOUR) / HEURE DE POINTE PROBABLE DANS UNE JOURNÉE D'ÉTÉ MOYENNE (VÉH / HEURE)	159	178	475	659	1060
PROBABLE PEAK HOUR ON 8 PEAK DAYS (VEH / HOUR) / HEURE DE POINTE PROBABLE DANS 8 JOURNÉES DE POINTE (VÉH / HEURE)	195	225	605	835	1330

NOTES

1. A 7% INCREASE WILL BE MAINTAINED FROM 1963 TO 1970 THIS IS SLIGHTLY LESS THAN THE CURRENT RATE OF INCREASE

2 A 30% INCREASE WILL OCCUR IMMEDIATELY FOLLOWING CONSTRUCTION OF THE CROSSING DUE TO INDUCED TRAFFIC

3 AND 4. FOR THE PERIOD FOLLOWING CONSTRUCTION OF THE CROSSING TWO ESTIMATES ARE SHOWN
3 - ASSUMES A CONTINUED 7% INCREASE UNTIL 1975 AND THEN AN ANNUAL GROWTH OF 3%.
4 - ASSUMES AN IMMEDIATE DROP TO AN ANNUAL GROWTH OF 3%
THESE TWO ASSUMPTIONS SHOW A BAND OF PROBABLE TRAFFIC FROM WHICH A MEAN GROWTH HAS BEEN DERIVED

SSAGE DU DÉTROIT DE NORTHUMBERLAND

VOLUME DE TRAFIC ANNUEL ANTICIPÉ JUSQU'EN 1995

GOUVERNEMENT DU CANADA
INISTÈRE DES TRAVAUX PUBLICS
HUMBERLAND CONSULTANTS LIMITED
MARS 1964 | PLANCHE 3

NORTHUMBERLAND STRAIT CROSSING

ANTICIPATED ANNUAL TRAFFIC VOLUME TO 1995

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS
NORTHUMBERLAND CONSULTANTS LIMITE
MARCH 1964 | PLATE 3

Traffic

Road Traffic — On the basis of the existing vehicle volume records at both Prince Edward Island ferry crossings and the Canso Causeway in Nova Scotia, it is reasonable to conclude that a two-lane crossing of Northumberland Strait will be loaded beyond design capacity possibly even within 25 years after its completion. This conclusion is based on an average growth rate in traffic volumes of 7 per cent per annum since 1955; an increase in traffic volume of approximately 30 per cent in the year immediately following construction of the crossing; and an annual increase of approximately 3 per cent per annum thereafter. The relation of these varying rates of growth to anticipated traffic volumes in future years in shown on Plate 3. In addition to this anticipated growth pattern, there are other factors which will have an effect on the future traffic loadings for the crossing, such as:

(a) The economic growth of Prince Edward Island following construction of the crossing.

(b) The general increase in tourism as a major form of recreation in North America.

(c) The overcrowding of recreational facilities in the Atlantic seaboard area of the United States.

(d) The possibility of moving freight to and from Prince Edward Island by truck transport instead of rail. The present annual rail freight movement is approximately 1,000,000 tons. The movement of this freight by truck transport will increase the crossing traffic by a minimum of 50,000 vehicles per annum.

The traffic capacity of a two-lane or four-lane road with 12-foot traffic lanes on the crossing will be affected by such things as operating speed, clearance from the edge of traffic lane to an obstruction, and the per cent of commercial vehicles in the stream of traffic. The effect of these factors on capacity is shown in the following table:

	Operating Speed — MPH					
	25-30	30-35	35-40	40-45	45-50	50-55
2-lane road						
shoulders 6 ft or more	1400	1600	1400	1150	900	600
shoulders 5 ft	1300	1500	1300	1100	850	550
shoulders 2 ft	1100	1300	1100	900	700	500
4-lane road with 4-ft outer shoulders and 4-ft median	3650	6800	5650	4700	3800	3000

The volumes shown above are practical or design capacities and are expressed in vehicles per hour, total both directions. These volumes will permit traffic to move without unreasonable delay, hazard, or restriction to the driver's freedom to manoeuvre under prevailing roadway and traffic conditions.

Depending on the per cent of commercial vehicles in the traffic stream, the capacities given above will be reduced by the following percentages.

Per Cent of Commercial Vehicles	Per Cent Reduction in Capacity 2-lane road	4-lane road
5	6	5
10	11	9
15	16	13

NOTE: Capacities have been calculated from data given in Manual of Geometric Design Standards for Canadian Roads and Streets — published by the Canadian Good Roads Association.

To proceed with detailed designs for the crossing, the following criteria must be established:

(a) Future peak hour demand, both with and without the railway.

(b) Design hour volume.

(c) Design speed.

(d) Operating speed.

To determine these criteria with confidence, it will be necessary to carry out the following studies:

(a) Origin and destination studies of traffic using the ferries.

(b) Protracted volume counts to determine peak hour, and daily factors.

(c) Delay studies to determine the time lost waiting for ferries.

(d) Studies of growth of population, and car and truck registration and usage, to determine suitable growth factors for traffic with the various origins indicated by the origin and destination studies.

(e) Studies of the before and after results of the construction of other causeways or crossings with similar characteristics.

Rail Traffic — The rail traffic to and from Prince Edward Island is carried on the ferry from Borden to Cape Tormentine. Statistics on the number of rail cars carried in recent years were obtained from the Department of Industry and Natural Resources at Charlottetown, and are given below:

Year	Railway Cars Carried
1958	56,987
1959	57,500
1960	56,234
1961	53,660
1962	49,559

Additional statistics from the same source show that in 1962, 11,579 loaded railway cars left the Island, of which 8,447 carried potatoes and 1,043 carried livestock. During the same year, 12,493 loaded railway cars entered the Island, the largest items being gas and oil carried by 1,826 cars, bricks and cement by 1,218 cars, and flour and feed by 1,042 cars. It is estimated that the tonnage of freight moved across the Strait in 1962 was in the order of one million. At present, there is a daily passenger train which crosses to the Island by ferry.

Marine Traffic — Northumberland Strait is open to marine traffic from mid-April to mid-December, and is primarily used by vessels of less than 10,000 tons. Trans-Atlantic ships and large vessels serving the eastern seaboard generally pass north of Prince Edward Island.

Statistics on the number of ships passing through the Strait are not complete, but the log of vessels arriving at and departing from Charlottetown indicates that traffic through the Strait is light, and that with present marine traffic volume an opening bridge over a navigation lock would not require to be raised more than twice a day, providing there are necessary clearances for local fishing and pleasure craft to pass under the structure.

There is little or no movement of the large trawler type fishing boat through the Northumberland Strait.

Most trawlers sail straight out from their home ports at the end of the Strait to fishing grounds in the Gulf of St. Lawrence. Lobster boats, however, travel extensively in the Strait so special provisions were considered that would facilitate their passage through the crossing.

For the complete rockfill crossings considered in Part II of this report, it is proposed to provide a passage for fishing vessels off Jourimain Island. This passage will be through a bridged opening with lock gates at each end. Correspondence with the Federal Department of Fisheries in February 1959 indicated that the size of fishing vessel to be considered in the design of the bridged opening is:

Maximum length	—	45 feet
Maximum beam	—	12 feet

A clearance of 10 feet at high water spring tides should also be provided. The above dimensions correspond to a large lobster boat, but are less than those of a trawler.

For bridge crossings considered in the Phase I studies the maximum current through openings between piers has been kept to less than 6 knots and sufficient clearance has been provided above high water springs so that small fishing boats and pleasure craft can normally pass under the bridge spans.

Further studies of government department records on marine traffic in the Strait will be made during Phase II, so that the number and types of vessels can be accurately determined. The basic data obtained will be used to assess the most suitable dimensions of locks or openings for the passage of ships through the causeway.

TYPES OF CROSSING

Various combinations of types of crossing have been investigated in the Phase I studies and for each of these, a cost estimate, a brief description, and a summary of advantages and disadvantages are presented in Part II of this report. Most of the proposals comprise a combination of basic structural elements and some components are common to a number of schemes.

It is the purpose of this section to describe in general terms these major elements, and to summarize the ways in which they have been combined to form the various schemes for the proposed crossing.

Rockfill Causeway

Most of the schemes presented in Part II of the report incorporate a section of rockfill causeway. Comparative estimates have shown that, considering only the direct cost of the causeway itself, and the capitalized cost of maintenance to repair damage due to ice and wave action during storms, a causeway constructed completely across the Strait would probably be the least expensive method of effecting a permanent crossing.

A number of very significant additional cost factors are, however, associated with this proposal, principally the cost of providing a navigation lock and the costs associated with the alteration in tidal regime caused by the construction of a virtually complete barrier across the Strait. When these additional cost factors are evaluated, it is apparent that a "full causeway" is not the optimum economic solution.

Nevertheless, because of the relatively low cost of rockfill causeway per unit length compared with the alternatives of bridging or tunnelling, there remains a strong economic incentive to incorporate in any scheme as long a rockfill causeway section as possible consistent with the maintenance of sufficient clear water area in the Strait to limit changes in the tidal regime to acceptable proportions.

The main body of the rockfill causeway would be constructed of local sandstone, which may be obtained in adequate quantity from the quarries located close to the site on both the New Brunswick and Prince Edward Island sides. A considerable amount of study already has been devoted to establishing the availability and characteristics of this rock in previous studies, notably those carried out by the Department of Public Works during the period 1956-1958.

To summarize the conclusions of these investigations very briefly, the rock, while not a particularly competent or durable variety of sandstone, would perform satisfactorily as bulk rockfill. A certain amount of settlement of the fill would, nevertheless, occur due to internal adjustment of the positions of the dumped rockfill fragments and a limited amount of crushing at points of contact between fragments. This process of internal consolidation and adjustment should, however, be virtually complete by the end of the period of construction, and little settlement need be anticipated after final grading of the causeway prior to construction of the travelled surfaces.

The results derived from drilling and seismic survey work in the Strait on the line of the proposed crossing show that the overburden above bedrock is nowhere thicker than 20 feet and comprises mainly

dense glacial till, with only a relatively thin superficial layer of reworked till or recent seabed sediments being present.

In general, the till encountered in exploratory work constitutes a perfectly adequate foundation for a rockfill of the height contemplated, and the upper layer of comparatively weak material would be rapidly displaced as the rockfill is placed. No major foundation problems need, therefore, be anticipated in construction of a rockfill causeway section.

It is at present contemplated that the lower portion of the rockfill would be constructed by dumping from marine equipment, and these methods would continue to be used until the fill reached a level such that the tidal fluctuations no longer permitted an economic working cycle for the marine equipment. Thereafter, the fill would be completed by end dumping from trunks.

The considerations concerning the economic causeway crest level and design criteria governing the choice of armour rock sizes are discussed in the previous section — Design Considerations — under the subtitle Hydraulic Aspects. For the purpose of the layouts and estimates presented herein, the causeway crest level has been set at 31 feet above low water ordinary spring tide (LWOST) at Borden.

As pointed out in the same section, the causeway's exposed position and the frequent incidence of rough water in the Strait necessitates careful and conservative design and construction of armour rock protection for the slopes of the fill in order to preclude displacement or erosion of the bulk fill materials by wave action.

The actual operating costs of the causeway could very largely be determined by the effectiveness of the armour rock protection in minimizing the frequency and extent of maintenance work. The studies performed to date indicate that the op-

timum economic balance between first cost and maintenance costs is attained with the use of armour rocks weighing between 6 and 9 tons.

The primary qualities desirable in armour rock are physical and chemical durability. It should be resistant to deterioration as a result of impact and abrasion, freezing and thawing, or wetting and drying cycles.

Although they are acceptable as rockfill materials, it is unlikely that the local sandstones would give satisfactory service as armour rock. Local sandstone from some of the more massive beds in the proposed quarries for bulk rockfill may, in the final analysis, prove to be suitable for armour rock, but at the present stage of the investigations it would appear unjustifiably optimistic to place much reliance on these sources. A number of possible armour rock quarries were investigated in the course of the Phase I studies, at least two potential sources of igneous or massive sedimentary rock suitable for use as armour stone being located within a reasonable distance from the site.

The armour rock protection would extend from the crest of the causeway to approximately an elevation 11 feet below low water ordinary spring tide, as indicated on the plates. Below this elevation, the severity of wave action is likely to reduce to a level at which less stringent slope protection measures are necessary, and here the smaller rock from the armour stone quarries can be employed as riprap together with any suitable material obtained from the local sandstone quarries worked for bulk fill. Thick transition zones comprising rock intermediate in size between the riprap or armour rock and the bulk fill would be incorporated.

During construction of the causeway, there will be long periods when the surface of the fill placed by

marine equipment may be subjected to erosive action due to surface waves and accelerated tidal flows over the restriction formed by the partially completed causeway section. To protect the surface until it is covered by a further lift placed by end dump trucks it may be necessary to place a mat of riprap on it as the final phase of the marine work on each section.

Bridge

In the preceding section, the undesirable effects on the tidal regime of constructing a complete barrier across the Strait were mentioned. One way of providing the desirable minimum clear water area, amounting to approximately 35 per cent of the present area of the narrows between Borden and Cape Tormentine, is to replace a portion of the causeway by a section of bridge. The length of bridge required to give the necessary area is about 4 miles, the structure being located more or less centrally in the Strait where the water is deepest, so as to give the necessary flow area with a minimum bridge length.

Previous studies have shown that the cost of a high level bridge, with one hundred and fifty feet of vertical clearance to allow the passage of shipping, was prohibitively expensive. Phase I investigations of a bridge section were, therefore, confined to the examination of a bridge providing a sufficient clearance above maximum high tide to allow passage of lobster boats and small craft, and prevent damages due to the pile up of ice around the bridge piers.

Two basic designs of bridge superstructure have been evolved. In those schemes designed to provide for both railway and road traffic, a double-deck steel truss, as shown on Plate 10 would appear to be the economic solution, the single-track railway being carried on stringers and cross beams framing into the lower chords of the trusses, while the concrete roadway deck is carried on the upper chords.

For this particular crossing, an arrangement comprising anchor spans with double cantilevers and suspended spans between the cantilevers probably represents the best form of articulation. This arrangement automatically permits relative settlement between piers without inducing secondary stresses in the superstructure, results in an economic design of superstructure, particularly for dead loading, and permits a high degree of standardization in fabrication.

The construction of the superstructure could proceed by conventional erection practices, working from previously erected sections with a small amount of temporary falsework. Alternatively, the anchor and suspended spans could be fabricated on shore, floated out on barges, and placed in position on the piers. Subsequently, secondary members, such as the deck stringers could be erected and the concrete road deck poured.

The layouts and estimates are based on spans of 350 feet between centres of piers. It is possible that more detailed studies would show that some economies could be effected by the use of high strength steels in the more highly stressed portions of the superstructure and somewhat longer spans, but the designs and cost estimates presented herein are considered to be sufficiently accurate for the purposes of the Phase I studies.

The advantage of long spans in the case of the prefabricated conical piers discussed in the following paragraphs is principally due to the fact that since these piers take up a large proportion of the flow area beneath the bridge, an increase in span results in a reduction of the number of piers and a substantially shorter total length of bridge to give the same flow area.

The design presented for a bridge to accommodate road traffic only is based on the use of simply supported prestressed concrete beams spanning about 300 feet between pier centres, as is shown for example on Plate 11. The roadway deck forms the upper flange of the beams, which would be cast and post-tensioned in a casting yard on shore, floated out on specially equipped barges, and placed in position on the

piers. Each beam is estimated to weigh approximately 1,700 tons. Preliminary comparative studies have been made between steel and concrete girders; however, further studies will be required to establish the merits of each type.

The form of pier tentatively selected for purposes of the Phase I designs and estimates for either type of bridge, consists essentially of a hollow precast concrete shell of conical form. Such a pier has the advantage that it can be floated out and sunk into place on a prepared foundation of sound granitic rockfill placed by bottom dump barges. Once the pier is in place, lean concrete is poured by tremie to fill the hollow shell. This will provide the necessary mass to render the pier stable against lateral forces due to ice, waves, and wind acting on the superstructure. The amount of underwater work will be reduced to an absolute minimum and extensive and time-consuming cofferdam or caisson construction of piers eliminated. The foundation of Prince Shoal lighthouse at the mouth of the Saguenay River in Quebec was constructed in 1962 in the manner just outlined.

The inclined face, which the conical pier presents to ice floes or rafts that could be blown towards it by the winds from any direction is advantageous, since the effect of lateral forces exerted on the pier are offset by vertical components tending to increase the stability of the pier against sliding upon its foundation. In addition the inclined reaction of the pier on the ice will tend to minimize the ice loads by causing the leading edge of the ice floe or raft to fail in combined shear flexure rather than in direct compression. Further study of the action of ice upon piers of this form will be carried out in Phase II.

One of the proposals presented in Part II of this report involves the construction of the bridge initially for two lanes of traffic with provision for a subsequent widening to four lanes if this becomes justified by the increase in traffic volume.

Initially, the width of the pier column caps will be sufficient to carry only one roadway beam. Provision will be made, however, to attach two cantilevers to each cap should the widening become necessary. The extended pier caps will be rendered monolithic by prestressing, the ducts for the prestressing cables being formed in the cap during initial construction. The basic concept is indicated on Plate 18.

The first set of roadway beams will be moved laterally across the widened column caps by jacking, several beams being jacked over concurrently so that in plan the roadway forms a continuous curve and is negotiable by traffic during the jacking process.

Once the first series of roadway beams have been relocated on the piers, the new beams carrying the additional two lanes of traffic will be installed on the caps in a manner similar to that used in initial construction, and described above.

Prefabricated Tunnel

A number of the schemes discussed in Part II of this report incorporate lengths of tunnel made up of prefabricated concrete units cast on shore, which are floated out into position, and sunk upon a prepared foundation on the bed of the Strait, or on a previously placed bed of rockfill.

The cost per unit length of such a tunnel is approximately three times that for a bridge designed to carry the same traffic, and consequently the use of a prefabricated tunnel for the proposed Northumberland Strait Crossing is contemplated only to provide a navigation opening of sufficient clear width at low tide to handle vessels which are too large to pass under the bridge.

A considerable number of precedents exist for the use of prefabricated tunnels of the type described, and which are shown on Plates 10 to 12. Notable examples among these are the Maas Tunnel in the Netherlands and the Deas Island Tunnel across the Fraser River, near Vancouver, B.C.

The tunnel will consist of precast, reinforced concrete elements, each about 350 feet long and weighing some 20,000 tons. The tunnel elements will be constructed inside a cofferdam built out into the Strait from the shore with temporary bulkheads incorporated to close the ends of the units. After completion of the prefabricated sections, the cofferdam will be breached and the units floated out to position in the Strait by means of a specially constructed assembly of steel barges braced together along the sides of the unit and equipped with winches for positioning of the assembly and control of the sinking operation.

After each unit is placed on the prepared foundation on the bottom of the Strait, it will be levelled by underwater jacking, the joints between adjacent units closed by jacking, and the assembly rendered monolithic and water-tight by in situ concreting of the joints. After final alignment of the units in this manner, sandfill will be jetted between the foundations and the undersides of the unit to give continuous support to the tunnel invert. The units will be subsequently covered and surrounded by fill placed from bottom dump barges to stabilize the tunnel and to prevent erosion of the sandfill under the tunnel by tidal flows.

The navigation channel will be located close to the Prince Edward Island shore. A considerable amount of underwater rock excavation will be required to form, at the proper grades, the trench in which the tunnel units are subsequently placed.

A number of different sections for the prefabricated tunnel are dealt with in Part II, corresponding to the various alternative traffic facilities considered. The basic concepts and methods of construction for all alternatives are, however, similar to those described above.

In the particular case of a two-lane highway, an alternative type of prefabricated tunnel has been considered. In this case, it is possible to employ techniques similar to those developed for the tunnel under the Galveston Ship Canal and the Chesapeake Bay Tunnels. This type of tunnel entails the use of

sections of double-walled circular steel tube constructed on shore, lined with concrete and with the roadway installed for ballast. These are towed out and sunk into position by pouring concrete into the space between the double walls. A section of this type of tunnel is shown on Plate 11.

Tunnel Driven in Rock

Schemes 4A to 4C presented in Part II, are based on the construction of a vehicular tunnel driven in rock and extending completely across the Strait. The length of the tunnel proper will be approximately seven miles for those schemes in which provision for road traffic only is made. Where provision for the railway is included, the tunnel length is increased by almost two miles due to the flatter gradients necessary at the approaches. The approaches to the tunnel on both the Prince Edward Island and New Brunswick sides will be constructed by open cut methods.

The tunnels will be driven through the gently dipping sandstone, siltstone, and mudstone beds underlying the Strait. The exploratory drilling performed to date indicates that faults or shear zones occur only infrequently. The rock, however, is not structurally strong and the tunnel excavation before lining will probably have to be supported over most of its length by steel sets and possibly rock bolts.

The magnitude of the problem which could be encountered in handling water seepage into the tunnel during construction cannot be predicted accurately with the limited knowledge presently available concerning the geohydrology of the rock formation in the area of the proposed crossing.

In the form of intact samples, the sandstone rock does not have a high permeability and the intact mudstone and siltstone is rather impervious. The bulk permeability of the rock mass, however, depends principally upon the spacing, degree of continuity, and extent of interconnection of open jointing or fracturing in the various strata, and also

upon the areal continuity of those strata such as the mudstone or siltstone layers which might act effectively as aquicludes.

It would appear from the results of the offshore drilling operations conducted during the summer of 1963, that the mudstone and siltstone layers are discontinuous. Consequently, recharge of groundwater in the rock mass below the Strait might not be significantly impeded by the presence of these layers. On the other hand, the layer of till overlying the rock does appear to be virtually continuous although variable in thickness. This may, in fact, prove to be an effective seepage barrier which could reduce ingress of water from the Strait to proportions which could be handled by pumping without great difficulty.

For purposes of the estimate presented in Part II of this report, fairly severe assumptions have been made concerning water conditions during construction, and high pumping costs have been included. As an example of conditions which might pertain, it may be noted that the Mersey Tunnel, driven through sandstone formation under the River Mersey, near Liverpool, England, required a continuous pumping capacity of 6,000 to 7,000 gpm throughout the period of underwater construction. The total length of the Mersey Tunnel is slightly over two miles, but the underwater section is only about a mile long.

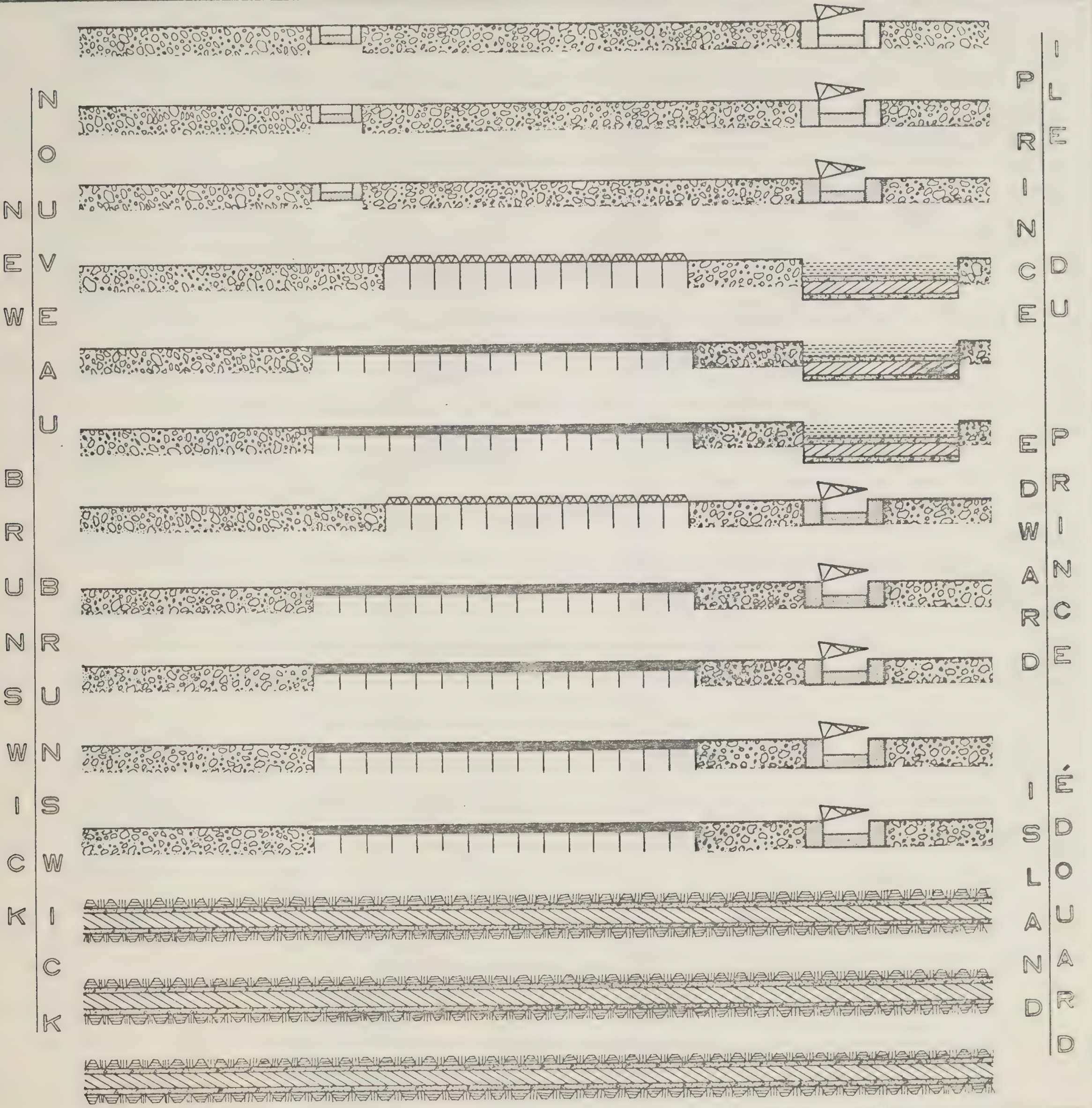
Selection of the depth of rock cover over the tunnel is an important economic consideration, since the deeper the tunnel, the greater its length and the length of the approaches to maintain acceptable gradients. The minimum necessary rock cover over the tunnel is governed by considerations of stability against collapse of the roof. If collapse were complete, flooding of the tunnel would inevitably result. Although there are instances of tunnels having been constructed under similar conditions with a very small rock cover, it is considered that, for the purposes of the Phase I studies, a cover of about twice the equivalent tunnel diameter is the minimum which could be contemplated on the basis of the geological information currently available. The layouts and estimates presented in Part II have been based on this assumption.

A number of different tunnel sections have been considered, corresponding to the various alternative traffic requirements. These are shown in Part II of this report. In each case, a large proportion of the cross-sectional area of the tunnel will be occupied by ventilation ducts. Ventilation of a tunnel of this length designed to carry fairly heavy motor vehicle traffic requires a very extensive and costly system. The estimated cost of the electrical and mechanical installation is in the order of $20 million for each of the various driven tunnel schemes. In the only other tunnel of comparable length in the world, the Mont Blanc Tunnel, the capacity is limited by the ventilation system to a maximum of 450 cars per hour.

SCHEMES INVESTIGATED

The various methods which have been discussed for constructing the crossing have been combined in a number of ways, and fourteen schemes are described in Part II of this report. The elements have been located within the length of the proposed crossing in a manner to fulfil the basic design concepts and yield maximum economy. Although each scheme is presented and discussed in Part II, the various basic arrangements and elements of the fourteen schemes considered are, for clarity, summarized diagrammatically on Plate 4, and their estimated cost and annual maintenance and operation costs given in the following table. An additional scheme was considered involving a partial rockfill causeway and prefabricated tunnel without a bridge section. While this combination had definite appeal in using only well proven methods of construction, the cost was prohibitive.

CONFIGURATION OF ELEMENTS
CONFIGURATION DES DIVERS ÉLÉMENTS



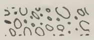
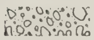
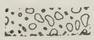
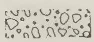
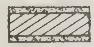
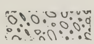
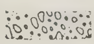
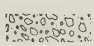
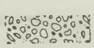
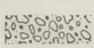
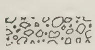
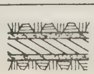
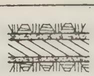
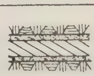
NORTHUMBERLAND STRAIT CROSSING

DIAGRAMMATIC REPRESENTATION OF SCHEMES FOR STRAIT CROSSING

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS

NORTHUMBERLAND CONSULTANTS LIMITED

MARCH 1964 | PLATE 4

SCHEME / OLUTION	TRAFFIC FACILITIES / FACILITÉS POUR TRAFIC	ROCKFILL CROSSING / PASSAGE EN ENROCHEMENT	UNDERGROUND ROCK DRIVEN TUNNEL / TUNNEL EXCAVÉ DANS LE ROC	PREFABRICATED CONCRETE TUNNEL / TUNNEL EN BÉTON PRÉFABRIQUÉ	STEEL TRUSS BRIDGE / PONT MÉTALLIQUE À POUTRES ARMÉES	PRESTRESSED CONCRETE BRIDGE / PONT EN BÉTON PRÉCONTRAINT	NAVIGATION CHANNEL / CANAL NAVIGABLE	BOAT NAVIGATION LOCK / ÉCLUSE POUR NAVIGATION DE FAIBLE TONNAGE	SHIP NAVIGATION LOCK AND OPENING BRIDGE / ÉCLUSE POUR NAVIGATION ET PONT - OUVRANT
1-A	TWO LANE HIGHWAY RAILWAY / ROUTE À DEUX VOIES CHEMIN DE FER								
1-B	TWO LANE HIGHWAY / ROUTE À DEUX VOIES								
1-C	FOUR LANE HIGHWAY / ROUTE À QUATRE VOIES								
2-A	TWO LANE HIGHWAY RAILWAY / ROUTE À DEUX VOIES CHEMIN DE FER								
2-B	TWO LANE HIGHWAY / ROUTE À DEUX VOIES								
2-C	FOUR LANE HIGHWAY / ROUTE À QUATRE VOIES								
3-A	TWO LANE HIGHWAY RAILWAY / ROUTE À DEUX VOIES CHEMIN DE FER								
3-B	TWO LANE HIGHWAY / ROUTE À DEUX VOIES								
3-C	FOUR LANE HIGHWAY / ROUTE À QUATRE VOIES								
3-D	TWO LANE HIGHWAY (28 FT. PAVEMENT) / ROUTE À DEUX VOIES CHAUSSÉE DE 28 PDS								
3-E	TWO LANE HIGHWAY CONVERTIBLE TO FOUR LANES / ROUTE À DEUX VOIES TRANSFORMABLE À QUATRE VOIES								
4-A	TWO LANE HIGHWAY RAILWAY / ROUTE À DEUX VOIES CHEMIN DE FER								
4-B	TWO LANE HIGHWAY / ROUTE À DEUX VOIES								
4-C	FOUR LANE HIGHWAY / ROUTE À QUATRE VOIES								

ASSAGE DU DÉTROIT DE NORTHUMBERLAND

REPRÉSENTATION SCHÉMATIQUE DES SOLUTIONS POUR LE PASSAGE DU DÉTROIT

GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS

RTHUMBERLAND CONSULTANTS LIMITED

MARS 1964 | PLANCHE 4

TABLE 4

Estimates of Cost, Operation and Maintenance

Scheme	Description	Estimated Total Cost (millions of dollars)	Annual Operation and Maintenance (thousands of dollars)	Capitalized Cost of Operation and Maintenance (millions of dollars) *
1 - Rockfill Causeway, comprising				
1 - A	Two-lane highway and railway	122	745	14.1
1 - B	Two-lane highway	116	710	13.4
1 - C	Four-lane highway	120	730	13.8
2 - Partial Rockfill Causeway, With Bridge on Prefabricated Piers, and Prefabricated Tunnel Sections, comprising				
2 - A	Two-lane highway and railway	146	930	17.6
2 - B	Two-lane highway	98	390	7.4
2 - C	Four-lane highway	109	620	11.7
3 - Partial Rockfill Causeway, With Bridge Section on Prefabricated Piers, and Navigation Lock comprising				
3 - A	Two-lane highway and railway	119	900	17.1
3 - B	Two-lane highway	87	465	8.8
3 - C	Four-lane highway	99	485	9.2
3 - D	Two-lane highway (28-foot pavement)	84	465	8.8
3 - E	Two-lane highway convertible to four lanes (Conversion cost — $17 million extra)	88	465	8.8
4 - Tunnel Driven in Rock, comprising				
4 - A	Two-lane highway and railway	148 - 158	1,050 - 1,100	19.8 - 19.1
4 - B	Two-lane highway	108	850	16.1
4 - C	Four-lane highway	170 - 180	1,500	28.4

* Operation and Maintenance costs capitalized at 5% for a 60-year period.

CONCLUSION AND RECOMMENDATIONS

A. The division of Northumberland Strait into two large bays by the construction of a complete rock-fill causeway would adversely change the tidal regime and increase the amplitude of storm surges. Phase I Report estimates of the cost of remedial works that would be required due to these changes total $23 million, and indicate that when these works are taken into account schemes allowing a clear flow area for tidal currents are competitive with a complete rockfill crossing.

It is, therefore, recommended that further engineering studies should be concentrated on crossings having a minimum effect on existing conditions in the Strait, provided that they are economically competitive with the complete rockfill causeway proposal, and can be designed to withstand successfully the effects of storms and ice action in the Strait.

B. Phase I engineering studies have shown that a crossing providing a clear flow area equal to about 35 per cent of the existing flow area in the narrows between Borden and Cape Tormentine will have virtually no effect on tides or storm surges in the strait. The maximum current through this clear area will be 5.9 knots during extreme spring tides and 4.0 knots during an average tide.

It is recommended that in comparing alternative design for the Northumberland Strait Crossing, a clear flow area should be allowed equal to 35 per cent of the existing flow area in the narrows.

C. Phase I engineering studies have shown that the flow area required to limit tidal effects and storm surges can most economically be provided by a section of bridge crossing carried on prefabricated piers.

It is recommended that the design for sections of bridge crossing on prefabricated piers be further developed.

D. Despite the advantage of a bridge crossing in providing flow area, the structural strength of rockfill causeway and its composition of largely local material make it an attractive and economical method of constructing part of the crossing.

It is recommended that the rockfill section of crossing be examined in greater detail, and the investigation of sources of construction material continued.

E. The report indicates the action of ice on the crossing as one of the principal factors to be considered in its design. Ice loads on piers of a bridge crossing can occur both from the impact of drifting of ice floes on collision with the pier, or from an ice jam blocking the opening between a number of piers.

It is recommended that measurements be taken of the thickness and strength of ice floes in the Strait and of ice forces on the pier at Borden. In addition, the future behaviour of ice in the vicinity of the crossing, when constructed, should be studied by tests on hydraulic models.

F. Phase I engineering studies have indicated that if provision is required for the uninterrupted flow of all marine and vehicular traffic, this can be most economically accomplished by placing a short section of prefabricated tunnel in the strait on the Prince Edward Island side of the crossing. A depth of 32 feet at low water would be provided in a navigation channel over the tunnel.

Offering a cost saving of at least $16 million, but not providing for the uninterrupted flow of all traffic, is a navigation lock. Vehicular traffic would cross the lock via an opening bridge. Preliminary studies show, however, that the volume of shipping through the strait is light, and opening of the bridge will not likely interrupt vehicular traffic more than about twice a day.

It is recommended that further studies should be made of the design and location of a lock to provide for the passage of shipping, and that subsurface exploration should be carried out at its favoured location.

G. Preliminary studies of road traffic have indicated that serious considerations should be given to providing facilities that would economically allow, by initial provision or later conversion, four lanes of vehicular traffic to pass over the crossing possibly within twenty-five years after its construcion.

It is recommended that further studies be made of vehicular and marine traffic at the crossing, so that sufficient data will be available to determine with confidence the facilities that should be provided for road, rail and marine traffic.

H. A preliminary study of a tunnel driven in rock under the strait indicated that this alternative is unattractive, both from the point of view of cost of construction and later maintenance and ventilation. The ventilation of this tunnel, which would be approximately eight miles long, might limit its capacity to handle peak volumes of traffic.

It is recommended that no further consideration be given to a tunnel crossing driven in rock.

NORTHUMBERLAND STRAIT CROSSING

PHASE I REPORT

Part II — Schemes for Northumberland Strait Crossing

ROCKFILL CROSSING, NAVIGATION LOCK WITH OPENING BRIDC
PASSAGE EN ENROCHEMENT, ÉCLUSE POUR NAVIGATION AVI PONT-OUVRANT

PLATE
PLANCHE 5

PRINCE EDWARD ISLAND
ILE DU PRINCE-EDOUARD

ROCKFILL CAUSEWAY

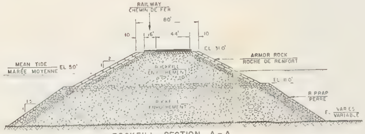
Description

In this general scheme a rockfill causeway across Northumberland Strait as shown on Plate 5 connects Jourimain Island, New Brunswick with Port Borden, Prince Edward Island.

The rockfill causeway which is approximately eight miles in length will be composed mainly of a bulk rockfill core obtained from sandstone quarries close to the site in both New Brunswick and Prince Edward Island. The core is protected to a depth of approximately 11 feet below LWOST by a 6-foot thick layer of armour rock units weighing approximately six to nine tons each. Below elevation -11 feet LWOST the core is protected by a 10-foot thick layer of random riprap. Armour rock can be obtained from known sources of durable rock in New Brunswick and, possibly, Nova Scotia. The crest width of the causeway will depend upon the type of facility provided, and is discussed later. The crest elevation of +31 feet LWOST has been chosen to restrict the frequency of overtopping by large waves to an average of approximately ten waves per annum. The upper section of the causeway, which is protected by armour units, has side slopes of 2 horizontal to 1 vertical, and the lower section side slopes are 1½ horizontal to 1 vertical. To provide for the movement of shipping through the Strait, a lock will be constructed near the Prince Edward Island shore. The Department of Transport requires lock dimensions of 820 feet by 80 feet with a depth of 32 feet over the sill at low water. A second smaller lock 60 feet long by 15 feet wide is provided for small vessels near the New Brunswick shore in accordance with Department of Fisheries requirements.

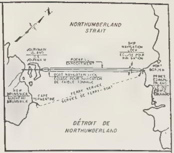
Advantages and Disadvantages

The structural strength of the rockfill causeway and its composition of largely local materials make it an attractive method of effecting a crossing, but there are several serious disadvantages. Dividing the Northumberland Strait into two large bays will change the tidal regime and increase flooding by storm surges. As a result remedial works along both shorelines will be necessary at a cost of at least $23 million. A careful evaluation of temperature changes and the effects on fisheries is necessary before this proposal can be adopted. The use of an opening bridge over the larger navigation lock to permit the passage of ships will, to a limited extent, impede the free flow of vehicles over the crossing.



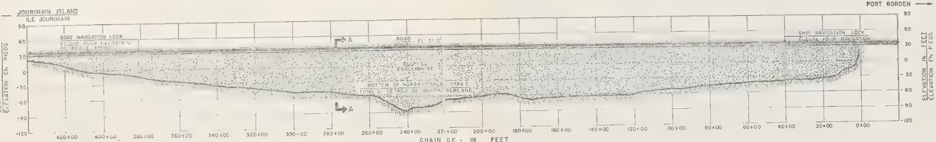
ROCKFILL SECTION A-A
ENROCHEMENT - COUPE A-A

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



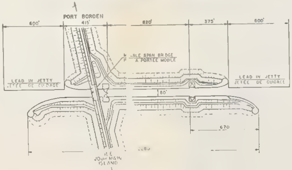
KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES



CHAINAGE - IN FEET
CHAINAGE EN PIEDS

PROFILE OF ROCKFILL CROSSING
PROFIL DU PASSAGE EN ENROCHEMENT



PLAN OF SHIP NAVIGATION LOCK
PLAN DE L'ÉCLUSE POUR NAVIGATION

SCALE / ÉCHELLE 300 0 300 FEET / PIEDS

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE–
   MAXIMUM = EL 10'
   MEAN = EL 5'
   MINIMUM = EL 0'

NOTES

1. TOUTES LES ÉLÉVATIONS MONTRÉES SUR CE DESSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE À PORT-BORDEN
2. LES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS AU-DESSOUS DES DONNÉES GÉODÉSIQUES CANADIENNES
3. AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
   MAXIMUM = ÉL 10'
   MOYENNE = ÉL 5'
   MINIMUM = ÉL 0'

NORTHUMBERLAND STRAIT CROSSING

SCHEME I-A

ROCKFILL CROSSING
TWO LANE HIGHWAY
RAILWAY
NAVIGATION LOCKS

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS

NORTHUMBERLAND CONSULTANTS LIMITED

MARCH 1964 | PLATE 6

PASSAGE DU DÉTROIT DE NORTHUMBERLAND

SOLUTION I-A

PASSAGE EN ENROCHEMENT
ROUTE À DEUX VOIES
CHEMIN DE FER
ÉCLUSES POUR NAVIGATION

GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS

NORTHUMBERLAND CONSULTANTS LIMITED

MARS 1964 | PLANCHE 6

SCHEME 1-A - Two-Lane Highway and Railway

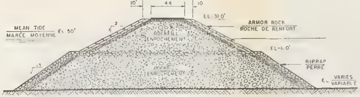
The general description which has been given for the rockfill causeway applies to this variation of the scheme as shown on Plate 6 opposite.

An overall crest width of 80 feet is provided under this proposal to accommodate two 12-foot traffic lanes with 10-foot paved shoulders and a single track rail right-of-way 16 feet wide. Armour protection extends 10 feet beyond the outer limits of the vehicular rights-of-way.

ESTIMATE OF COST

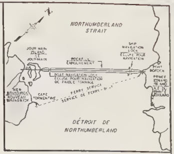
Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Bulk Fill	C.y.	28,913,000	$ 1.50	$ 43.370
Armour Rock				
Class A	C.y.	581,000	15.00	8.715
Class B	C.y.	1,162,000	7.50	8.715
Random Riprap	C.y.	2,936,000	6.00	17.616
Locks	—	—	Sum	8.830
Remedial Works	—	—	Sum	23.000
Miscellaneous	—	—	Sum	5.575
Subtotal				115.841
Engineering and Supervision at 5 per cent				6.159
TOTAL				$ 122.000

The estimated annual operating and maintenance cost is $745,000.



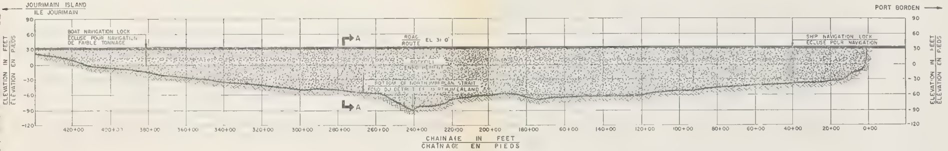
ROCKFILL SECTION A–A
ENROCHEMENT – COUPE A–A

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES



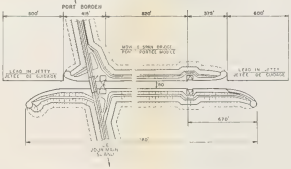
PROFILE OF ROCKFILL CROSSING
PROFIL DU PASSAGE EN ENROCHEMENT

NOTES

1. TOUTES LES ÉLÉVATIONS MONTRÉES SUR CE DESSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE À PORT-BORDEN
2. LES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS AU-DESSOUS DES DONNÉES GÉODÉSIQUES CANADIENNES
3. AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
   MAXIMUM = ÉL. 10'
   MOYENNE = ÉL. 5'
   MINIMUM = ÉL. 0

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE–
   MAXIMUM = EL. 10'
   MEAN = EL. 5'
   MINIMUM = EL. 0'



PLAN OF SHIP NAVIGATION LOCK
PLAN DE L'ÉCLUSE POUR NAVIGATION

SCALE / ÉCHELLE 300 0 300 FEET / PIEDS

PASSAGE DU DÉTROIT DE NORTHUMBERLAND	
SOLUTION I-B	
PASSAGE EN ENROCHEMENT ROUTE À DEUX VOIES ÉCLUSES POUR NAVIGATION	
GOUVERNEMENT DU CANADA MINISTÈRE DES TRAVAUX PUBLICS	
NORTHUMBERLAND CONSULTANTS LIMITED	
MARS 1964	PLANCHE 7

NORTHUMBERLAND STRAIT CROSSING	
SCHEME I-B	
ROCKFILL CROSSING TWO LANE HIGHWAY NAVIGATION LOCKS	
GOVERNMENT OF CANADA DEPARTMENT OF PUBLIC WORKS	
NORTHUMBERLAND CONSULTANTS LIMITED	
MARCH 1964	PLATE 7

SCHEME 1-B - Two-Lane Highway

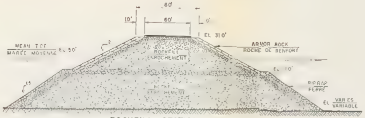
The general description which has been given for the rockfill causeway applies to this variation of the scheme, as shown on Plate 7 opposite.

An overall crest width of 64 feet is provided under this proposal to accommodate two 12-foot traffic lanes with 10-foot paved shoulders. Armour protection extends 10 feet beyond the outer limits of the vehicular right-of-way.

ESTIMATE OF COST

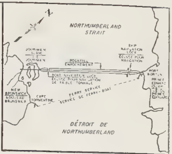
Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Bulk Fill	C.y.	26,910,000	$ 1.50	$ 40.365
Armour Rock				
Class A	C.y.	581,000	15.00	8.715
Class B	C.y.	1,162,000	7.50	8.715
Random Riprap	C.y.	2,856,000	6.00	17.136
Locks	—	—	Sum	8.830
Remedial Works	—	—	Sum	23.000
Miscellaneous	—	—	Sum	3.396
Subtotal				110.137
Engineering and Supervision at 5 per cent				5.863
TOTAL				$ 116.000

The estimated annual operating and maintenance cost is $710,000.



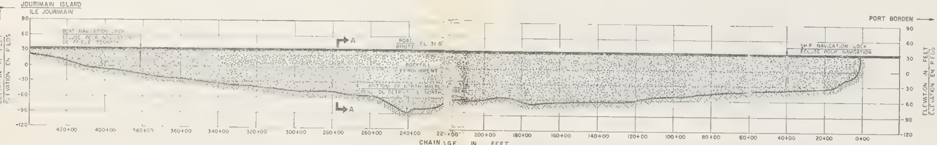
ROCKFILL SECTION A-A
ENROCHEMENT - COUPE A-A

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES

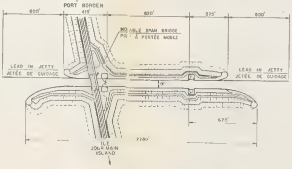


CHAINAGE IN FEET
CHAINAGE EN PIEDS

PROFILE OF ROCKFILL CROSSING
PROFIL DU PASSAGE EN ENROCHEMENT

NOTES

1. TOUTES LES ÉLÉVATIONS MONTRÉES SUR CE DESSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE À PORT-BORDEN
2. LES BASSES EAUX DE SYZYGIE SONT À 49 PIEDS AU-DESSOUS DES DONNÉES GÉODÉSIQUES CANADIENNES
3. AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
   MAXIMUM = ÉL 10'
   MOYENNE = ÉL 5'
   MINIMUM = ÉL 0'



PLAN OF SHIP NAVIGATION LOCK
PLAN DE L'ÉCLUSE POUR NAVIGATION

SCALE / ÉCHELLE 300 0 300 FEET / PIEDS

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE—
   MAXIMUM = EL 10'
   MEAN = EL 5'
   MINIMUM = EL 0'

PASSAGE DU DÉTROIT DE NORTHUMBERLAND

SOLUTION I-C

PASSAGE EN ENROCHEMENT
ROUTE À QUATRE VOIES
ÉCLUSES POUR NAVIGATION

GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS

NORTHUMBERLAND CONSULTANTS LIMITED

MARS 1964 | PLANCHE 8

NORTHUMBERLAND STRAIT CROSSING

SCHEME I-C

ROCKFILL CROSSING
FOUR LANE HIGHWAY
NAVIGATION LOCKS

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS

NORTHUMBERLAND CONSULTANTS LIMITED

MARCH 1964 | PLATE 8

SCHEME 1-C - Four-Lane Highway

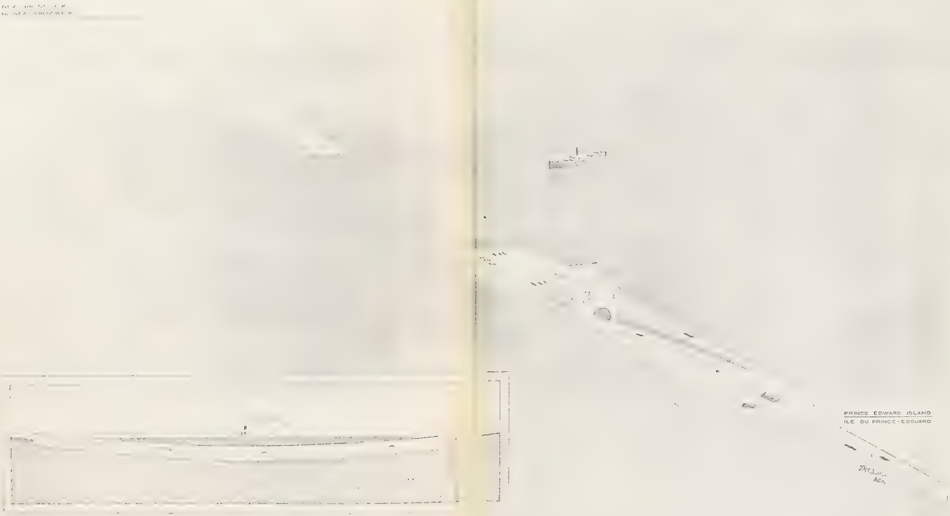
The general description which has been given for the rockfill causeway applies to this variation of the scheme, as shown on Plate 8 opposite.

An overall crest width of 80 feet is provided under this proposal to accommodate four 12-foot traffic lanes with opposing traffic separated by a barricaded 4-foot median and having 4-foot paved outer shoulders. Armour protection extends 10 feet beyond the outer limits of the vehicular right-of-way.

ESTIMATE OF COST

Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Bulk Fill	C.y.	28,913,000	$ 1.50	$ 43.470
Armour Rock				
Class A	C.y.	581,000	15.00	8.715
Class B	C.y.	1,162,000	7.50	8.715
Random Riprap	C.y.	2,936,000	6.00	17.616
Locks	—	—	Sum	8.830
Remedial Works	—	—	Sum	23.000
Miscellaneous	—	—	Sum	3.865
Subtotal				114.111
Engineering and Supervision at 5 per cent				5.889
TOTAL				$ 120.000

The estimated annual operating and maintenance cost is $730,000.



PARTIAL ROCKFILL, BRIDGE AND PREFABRICATED TUNNEL UND OPEN NAVIGATION CHANNEL
ENROCHEMENT PARTIEL, PONT ET TUNNEL PRÉFABRIQUÉ LE CANAL NAVIGABLE OUVERT

PLATE
PLANCHE 9

PARTIAL ROCKFILL CAUSEWAY WITH BRIDGE ON PREFABRICATED PIERS, AND A PREFABRICATED TUNNEL SECTION

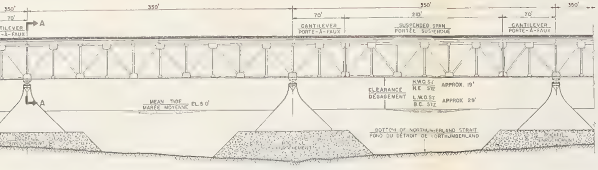
Description

This general scheme as shown on Plate 9 opposite has three components; a section of rockfill causeway, a bridge on prefabricated piers, and a prefabricated concrete tunnel. The crossing will connect Jourimain, New Brunswick with Port Borden, Prince Edward Island, a distance of approximately eight miles.

A major feature of the design is the section of bridge which crosses the deepest part of the Strait. It will consist of a series of concrete or steel bridge spans supported on prefabricated concrete piers, which are founded on submerged islands of rockfill. The rockfill causeway section extends from the New Brunswick shore to the bridge. An artificial rockfill island forms the northern abutment of the bridge and the southern portal of the prefabricated concrete tunnel which will pass beneath the navigation opening to the Prince Edward Island shore. This navigation opening provides a minimum depth of 32 feet below LWOST over a width of 1,000 feet. To minimize currents and tidal effects, the design provides for an opening of approximately 35 per cent of the original area of the Narrows.

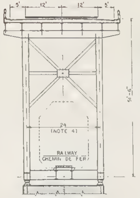
Advantages and Disadvantages

The use of a bridge and tunnel in part of the Northumberland Strait Crossing to provide an opening of 35 per cent of the original cross section of the Narrows will eliminate the danger of flooding due to increased tides and storm surges. The use of a tunnel under the navigation opening, as opposed to an opening bridge should result in uninterrupted flow of both vehicular and water-borne traffic. Small fishing boats and pleasure craft can normally pass under the bridge spans. Since this scheme incorporates a tunnel, it will require a staff on duty twenty-four hours a day to maintain the ventilating equipment and deal with accidents or breakdown of vehicles in the tunnel. These additional operating expenses are reflected in the cost estimates.



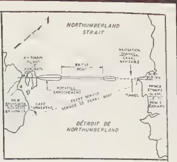
ELEVATION OF BRIDGE
ÉLÉVATION DU PONT

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



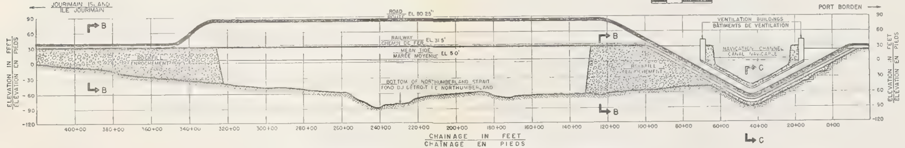
SECTION A-A
COUPE A-A

SCALE / ÉCHELLE 10 0 10 FEET / PIEDS



KEY PLAN
PLAN CLÉ

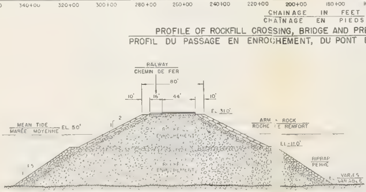
SCALE / ÉCHELLE 2 0 2 MILES / MILLES



PROFILE OF ROCKFILL CROSSING, BRIDGE AND PREFABRICATED TUNNEL
PROFIL DU PASSAGE EN ENROCHEMENT, DU PONT ET DU TUNNEL PRÉFABRIQUÉ

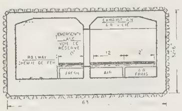
NOTES

1. TOUTES LES ÉLÉVATIONS MONTRÉES SUR CE DESSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE À PORT-BORDEN
2. LES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS AU-DESSOUS DES DONNÉES GÉODÉSIQUES CANADIENNES
3. AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
   MAXIMUM = ÉL. 10'
   MOYENNE = ÉL. 5'
   MINIMUM = ÉL. 0'
4. SI LA ROUTE REMPLACE LE CHEMIN DE FER -
   (a) LARGEUR DE 24' POUR ROUTE À UNE VOIE
   (b) LARGEUR DE 30' POUR ROUTE À DEUX VOIES



ROCKFILL SECTION B-B
ENROCHEMENT - COUPE B-B

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



TUNNEL SECTION C-C
TUNNEL - COUPE C-C

SCALE / ÉCHELLE 10 0 10 FEET / PIEDS

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE -
   MAXIMUM = EL. 10'
   MEAN = EL. 5'
   MINIMUM = EL. 0'
4. IF RAILWAY REPLACED BY HIGHWAY -
   (a) WIDTH IS 24' FOR ONE LANE HIGHWAY
   (b) WIDTH IS 30' FOR TWO LANE HIGHWAY

PASSAGE DU DÉTROIT DE NORTHUMBERLAND

SOLUTION 2-A

PASSAGE PARTIEL EN ENROCHEMENT
PONT
TUNNEL PRÉFABRIQUÉ
ROUTE À DEUX VOIES
ET CHEMIN DE FER

GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS
NORTHUMBERLAND CONSULTANTS LIMITED
MARS 1964 | PLANCHE 10

NORTHUMBERLAND STRAIT CROSSING

SCHEME 2-A

PARTIAL ROCKFILL CROSSING
BRIDGE
PREFABRICATED TUNNEL
TWO LANE HIGHWAY
AND RAILWAY

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS
NORTHUMBERLAND CONSULTANTS LIMITED
MARCH 1964 | PLATE 10

SCHEME 2-A - Two-Lane Highway and Railway

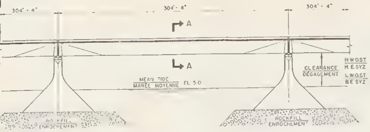
The general description which has been given for the partial rockfill causeway applies to this variation of the scheme as shown on Plate 10 opposite.

The rockfill section extends from the New Brunswick shore for approximately two miles and is similar to that described under Scheme 1-A. It adjoins the bridge section, nearly four miles long consisting of a series of cantilevered steel trusses with a span of approximately 350 feet. To avoid adverse railway gradients in the transitions at each end the railway is carried on the lower chords of the trusses with the highway on the upper chords. This location of the highway minimizes the hazard caused by freezing spray. The highway consists of two 12-foot traffic lanes with 5-foot outer safety lanes making a pavement width of 34 feet. The lower bridge chords are spaced so that the railroad can be converted to two 12-foot traffic lanes thus making the bridge a four-lane facility. The tunnel section is about two miles long including approaches with the tunnel itself extending 5,600 feet. The prefabricated elements are divided into two parts with 12-foot traffic lanes in one part and the railroad and an emergency traffic lane in the adjacent symmetrical part. Provision is made for converting the latter to two 12-foot traffic lanes to provide a four-lane facility.

ESTIMATE OF COST

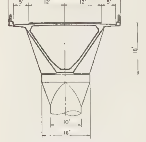
Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Rockfill Causeway	—	—	Sum	$ 13.798
Bridge				
Granitic Fill	C.y.	2,420,000	$ 5.00	12.100
Piers	Each	57	228,000.00	12.996
Bridge	L.f.	19,600	1,815.00	35.574
Prefabricated Tunnel				
Tunnel Elements	L.f.	5,600	3,000.00	16.800
Armour Rock and Fill	—	—	Sum	22.458
Miscellaneous	—	—	Sum	25.064
Subtotal				138.790
Engineering and Supervision at 5 percent				7.210
TOTAL				$146.000

The estimated annual operating and maintenance cost is $930,000.



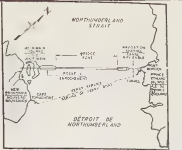
ELEVATION OF BRIDGE
ÉLÉVATION DU PONT

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



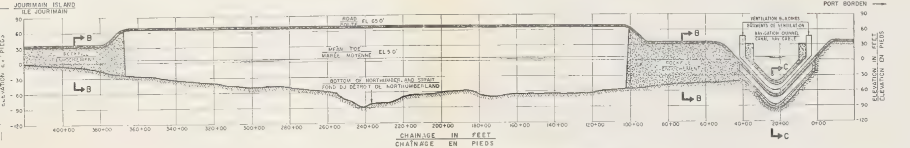
SECTION A-A
COUPE A-A

SCALE / ÉCHELLE 10 0 10 FEET / PIEDS



KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES



PROFILE OF ROCKFILL CROSSING, BRIDGE AND PREFABRICATED TUNNEL
PROFIL DU PASSAGE EN ENROCHEMENT, DU PONT ET DU TUNNEL PRÉFABRIQUÉ

NOTES

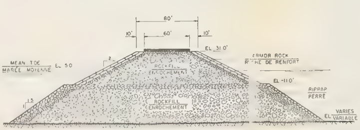
1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE– MAXIMUM = EL. 10' MEAN = EL. 5' MINIMUM = EL. 0'
4. NAVIGATION CHANNEL– WIDTH 1000 FEET, MINIMUM DEPTH 36 FEET AT MEAN TIDE

LES ÉLÉVATIONS MONTRÉES SUR CE ... SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE ... BORDEN

...ES EAUX DE SYZYGIE SONT À 4.9 PIEDS ...SOUS DES DONNÉES GÉODÉSIQUES ...NES

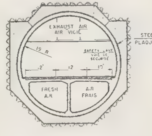
... EXTRÊME APPROXIMATIVE DE LA MARÉE MAXIMUM = ÉL. 10' MOYENNE = ÉL. 5' MINIMUM = ÉL. 0'

...VIGABLE – LARGEUR 1000 PIEDS, PROFONDEUR MINIMUM 36 PIEDS À MARÉE MOYENNE



ROCKFILL SECTION B-B
ENROCHEMENT - COUPE B-B

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



TUNNEL SECTION C-C
TUNNEL - COUPE C-C

SCALE / ÉCHELLE 10 0 10 FEET / PIEDS

...U DÉTROIT DE NORTHUMBERLAND
...LUTION 2-B
... PARTIEL EN ENROCHEMENT
PONT
...TUNNEL PRÉFABRIQUÉ
...ROUTE À DEUX VOIES
...VERNEMENT DU CANADA
...ÈRE DES TRAVAUX PUBLICS
...LAND CONSULTANTS LIMITED
... 1964 | PLANCHE 11

NORTHUMBERLAND STRAIT CROSSING

SCHEME 2-B

PARTIAL ROCKFILL CROSSING
BRIDGE
PREFABRICATED TUNNEL
TWO LANE HIGHWAY

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS
NORTHUMBERLAND CONSULTANTS LIMITED
MARCH 1964 | PLATE 11

SCHEME 2-B - Two-Lane Highway

The general description which has been given for the partial rockfill causeway applies to this variation of the scheme as shown on Plate 11 opposite.

The rockfill section extends from the New Brunswick side for approximately one mile and has a 64-foot crest width to accommodate two 12-foot traffic lanes with 10-foot paved shoulders. The bridge section is approximately five miles long and consists of single prefabricated concrete or steel box girders spanning approximately 300 feet. The width will be 34 feet providing two 12-foot traffic lanes and two 5-foot outer safety lanes. The elimination of the railway permits the use of increased gradients in the tunnel section thus reducing the length of tunnel and depressed approaches to approximately 6,000 feet, 3,860 feet being the length of the tunnel elements.

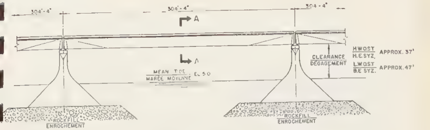
Between the tunnel section and the bridge section is incorporated approximately 4,000 feet of rockfill causeway. Tunnel width is 34 feet including two 12-foot traffic lanes and a 10-foot truck climbing lane.

Attention is drawn to the fact that, if it should be necessary to increase the capacity of this two-lane facility to four lanes at a later date, substantial additional expense will be necessary to duplicate the submerged tunnel.

ESTIMATE OF COST

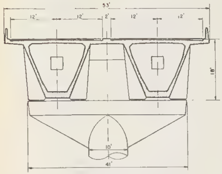
Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Rockfill Causeway	—	—	$ Sum	$ 10.639
Bridge				
Granitic Fill	C.y.	3,830,000	5.00	19.150
Piers	Each	89	228,000.00	20.292
Bridge	L.f.	26,752	550.00	14.714
Prefabricated Tunnel				
Tunnel Elements	L.f.	3,860	2,000.00	7.720
Fill and Armour Rock	—	—	Sum	9.605
Miscellaneous	—	—	Sum	11.548
Subtotal				93.668
Engineering and Supervision at 5 per cent				4.332
TOTAL				$ 98.000

The estimated annual operating and maintenance cost is $390,000.



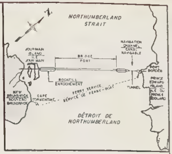
ELEVATION OF BRIDGE
ÉLÉVATION DU PONT

SCALE ÉCHELLE 40 0 40 FEET PIEDS



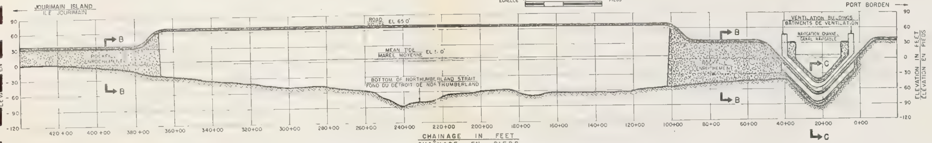
SECTION A-A
COUPE A-A

SCALE ÉCHELLE 10 0 10 FEET PIEDS



KEY PLAN
PLAN CLÉ

SCALE ÉCHELLE 2 0 2 MILES MILLES



PROFILE OF ROCKFILL CROSSING, BRIDGE AND PREFABRICATED TUNNEL
PROFIL DU PASSAGE EN ENROCHEMENT, DU PONT ET DU TUNNEL PRÉFABRIQUÉ

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN

2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)

3. APPROXIMATE EXTREME TIDAL RANGE-
MAXIMUM = EL 10'
MEAN = EL 5'
MINIMUM = EL 0'

4. NAVIGATION CHANNEL- WIDTH 1000 FEET
MINIMUM DEPTH 36 FEET
AT MEAN TIDE

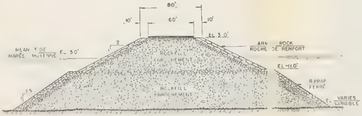
…TES

…OUTES LES ÉLÉVATIONS MONTRÉES SUR CE …ESSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE À PORT-BORDEN

…ES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS …U-DESSOUS DES DONNÉES GÉODÉSIQUES …ANADIENNES

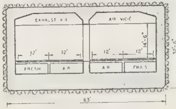
…AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MAREE
MAXIMUM = ÉL 10'
MOYENNE = ÉL 5'
MINIMUM = ÉL 0'

…CANAL NAVIGABLE - LARGEUR 1000 PIEDS
PROFONDEUR MINIMUM 36 PIEDS
À MARÉE MOYENNE



ROCKFILL SECTION B-B
ENROCHEMENT - COUPE B-B

SCALE ÉCHELLE 40 0 40 FEET PIEDS



TUNNEL SECTION C-C
TUNNEL - COUPE C-C

SCALE ÉCHELLE 10 0 10 FEET PIEDS

…SAGE DU DÉTROIT DE NORTHUMBERLAND	
SOLUTION 2-C	
…SSAGE PARTIEL EN ENROCHEMENT PONT TUNNEL PRÉFABRIQUÉ ROUTE À QUATRE VOIES	
GOUVERNEMENT DU CANADA …NISTERE DES TRAVAUX PUBLICS	
…THUMBERLAND CONSULTANTS LIMITED	
…ARS 1964	PLANCHE 12

NORTHUMBERLAND STRAIT CROSSING	
SCHEME 2-C	
PARTIAL ROCKFILL CROSSING BRIDGE PREFABRICATED TUNNEL FOUR LANE HIGHWAY	
GOVERNMENT OF CANADA DEPARTMENT OF PUBLIC WORKS	
NORTHUMBERLAND CONSULTANTS LIMITED	
MARCH 1964	PLATE 12

SCHEME 2-C - Four-Lane Highway

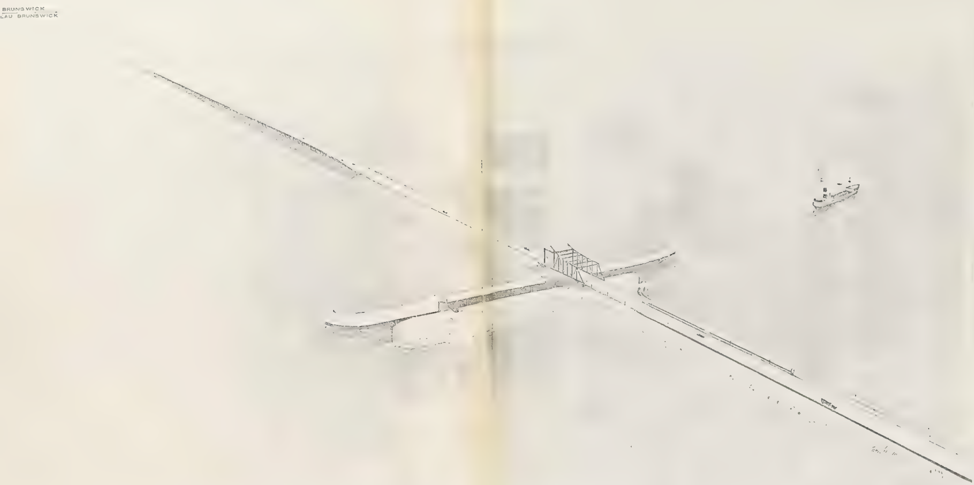
The general description which has been given for the partial rockfill causeway applies to this variation of the scheme as shown on Plate 12 opposite.

The rockfill causeway section extending from the New Brunswick shore is approximately two miles in length with a crest of 80 feet to accommodate four 12-foot traffic lanes with opposing traffic separated by a 4-foot barricaded median and having 4-foot paved outer shoulders. The bridge section is approximately four miles long composed of twin prefabricated concrete or steel box girders spanning approximately 300 feet and carrying two 12-foot traffic lanes on each girder. The tunnel section totals approximately 6,000 feet including approaches with the tunnel itself extending for 3,860 feet and carrying four 12-foot traffic lanes. A section of artificial rockfill island is situated between the tunnel and the bridge to carry the depressed tunnel approach and the ramp to the bridge deck.

ESTIMATE OF COST

Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Rockfill Causeway	—	—	$ Sum	$ 18.917
Bridge				
Granitic Fill	C.y.	2,860,000	5.00	14.300
Piers	Each	67	228,000.00	15.276
Bridge	L.f.	20,064	950.00	19.061
Prefabricated Tunnel				
Tunnel Elements	L.f.	3,860	3,000.00	11.580
Fill and Armour Rock	—	—	Sum	10.214
Miscellaneous	—	—	Sum	16.385
Subtotal				105.733
Engineering and Supervision at 5 per cent				5.267
TOTAL				$ 111.000

The estimated annual operating and maintenance cost is $620,000.



PARTIAL ROCKFILL, BRIDGE AND NAVIGATION OPENING WITH OPENING BRIDGE
ENROCHEMENT PARTIEL, PONT ET OUVERTURE NAVIGABLE AVEC PONT-OUVRANT

PLATE
PLANCHE 13

PRINCE EDWARD ISLAND
ILE DU PRINCE-ÉDOUARD

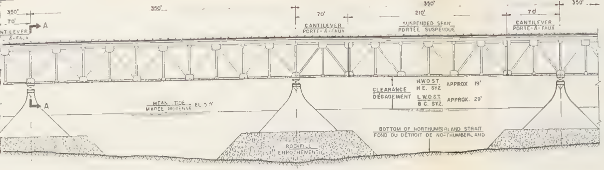
PARTIAL ROCKFILL CAUSEWAY WITH BRIDGE ON PREFABRICATED PIERS, AND A NAVIGATION LOCK

Description

This general scheme, as shown on Plate 13 opposite, consists of a rockfill causeway extending from each shore with a central bridge section approximately five miles long. The combined length of rockfill causeways is approximately 19,500 feet. The crossing will connect Jourimain Island, New Brunswick, and Port Borden, Prince Edward Island. At a point near the Prince Edward Island shore, in sufficient depth of water, a navigation lock 80 feet wide is provided for large vessels. This lock provides a minimum depth of 32 feet below LWOST and is crossed by an opening bridge. The bridge spans are supported on prefabricated concrete piers founded on submerged islands of rockfill. To minimize currents and tidal effects, the design provides an opening of approximately 35 per cent of the original cross sectional area of the Narrows. Small fishing boats and pleasure craft can normally pass under the bridge.

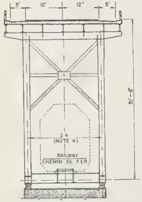
Advantages and Disadvantages

This scheme, like Scheme 2, eliminates the danger of flooding due to increased high tide levels and storm surges. The crossing of the navigation lock by an opening bridge will cause periodic stoppages of vehicular traffic during the shipping season. Furthermore, in periods of bad weather, it may be necessary for vessels to wait until conditions improve before attempting to negotiate the navigation lock. The substitution of the navigation lock for the submerged tunnel of Scheme 2 results in a reduced first cost and lower maintenance costs for comparable facilities at the expense of the interruption to traffic already mentioned. This type of scheme has the advantage that increased capacity can be obtained economically by adding duplicate spans between the piers of the open causeway, as indicated in Scheme 3-E.



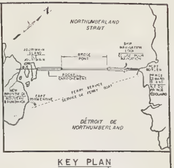
ELEVATION OF BRIDGE
ÉLÉVATION DU PONT

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



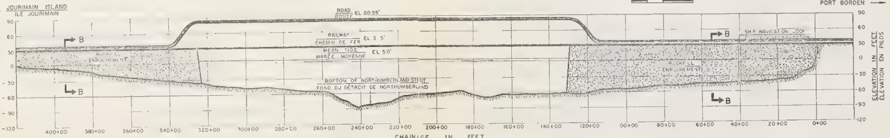
SECTION A-A
COUPE A-A

SCALE / ÉCHELLE 10 0 10 FEET / PIEDS



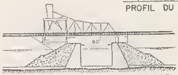
KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES



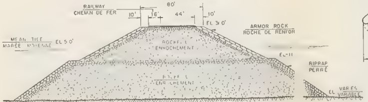
CHAINAGE IN FEET
CHAÎNAGE EN PIEDS

PROFILE OF ROCKFILL CROSSING, AND BRIDGE
PROFIL DU PASSAGE EN ENROCHEMENT, ET DU PONT



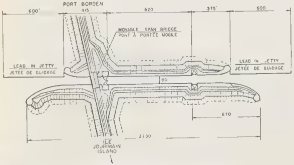
ELEVATION OF OPENING BRIDGE
ÉLÉVATION DU PONT MOBILE

SCALE / ÉCHELLE 80 0 80 FEET / PIEDS



ROCKFILL SECTION B-B
ENROCHEMENT - COUPE B-B

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



PLAN OF SHIP NAVIGATION LOCK
PLAN DE L'ÉCLUSE POUR NAVIGATION

SCALE / ÉCHELLE 300 0 300 FEET / PIEDS

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD) AT PORT BORDEN
3. APPROXIMATE EXTREME TIDAL RANGE -
   MAXIMUM = EL 10'
   MEAN = EL. 5'
   MINIMUM = EL 0'
4. IF RAILWAY REPLACED BY HIGHWAY -
   (a) WIDTH IS 24' FOR ONE LANE HIGHWAY
   (b) WIDTH IS 30' FOR TWO LANE HIGHWAY

...TES

...TES LES ÉLÉVATIONS MONTRÉES SUR CE ...SIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE ...ORT-BORDEN

...ES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS ...-DESSOUS DES DONNÉES GÉODÉSIQUES ...ADIENNES

...LITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
MAXIMUM = EL 10'
MOYENNE = EL 5'
MINIMUM = EL 0'

...LA ROUTE REMPLACE LE CHEMIN DE FER -
(a) LARGEUR DE 24' POUR ROUTE À UNE VOIE
(b) LARGEUR DE 30' POUR ROUTE À DEUX VOIES

NORTHUMBERLAND STRAIT CROSSING

SCHEME 3-A

PARTIAL ROCKFILL CROSSING
BRIDGE
OPENING BRIDGE
TWO LANE HIGHWAY
AND RAILWAY

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS

NORTHUMBERLAND CONSULTANTS LIMITED

MARCH 1964 | PLATE 14

...AGE DU DÉTROIT DE NORTHUMBERLAND

SOLUTION 3-A

...AGE PARTIEL EN ENROCHEMENT
PONT
PONT MOBILE
ROUTE À DEUX VOIES
ET CHEMIN DE FER

GOUVERNEMENT DU CANADA
...NISTÈRE DES TRAVAUX PUBLICS

...UMBERLAND CONSULTANTS LIMITED

...ARS 1964 | PLANCHE 14

SCHEME 3-A - Two-Lane Highway and Railway

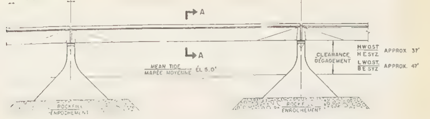
The general description which has been given for the partial rockfill causeway, bridge on prefabricated piers, and a navigation lock applies to this variation of the scheme as shown on Plate 14 opposite.

The rockfill causeway section is similar to that described under Scheme 1-A. The bridge section consists of a series of cantilevered steel trusses with a span of approximately 350 feet. To avoid adverse railroad gradients in the transitions at each end of the bridge section, the railroad is carried on the lower chords of the trusses with the highway on the upper chords. This location of the highway minimizes the hazard caused by freezing spray. The highway consists of two 12-foot traffic lanes with 5-foot outer safety lanes making a pavement width of 34 feet. The lower bridge chords are spaced so that the railroad can be converted to two 12-foot traffic lanes, thus making the bridge a four-lane facility.

ESTIMATE OF COST

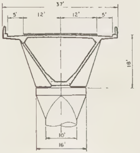
Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Rockfill Causeway	—	—	$ Sum	$ 20.238
Bridge				
Granitic Fill	C.y.	3,260,000	5.00	16.300
Piers	Each	77	228,000.00	17.556
Bridge	L.f.	26,600	1,815.00	48.279
Navigation Lock	—	—	Sum	8.830
Miscellaneous	—	—	Sum	2.633
Subtotal				$ 113.836
Engineering and Supervision at 5 per cent				5.164
TOTAL				$ 119.000

The estimated annual operating and maintenance cost is $900,000.



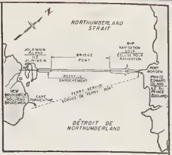
ELEVATION OF BRIDGE
ELEVATION DU PONT

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



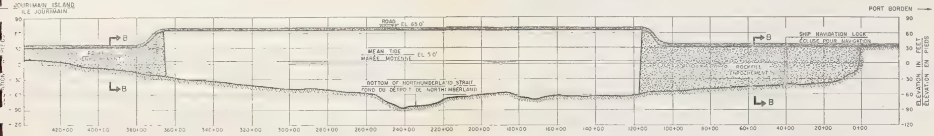
SECTION A-A
COUPE A-A

SCALE / ÉCHELLE 10 0 10 FEET / PIEDS



KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES



CHAINAGE IN FEET
CHAINAGE EN PIEDS

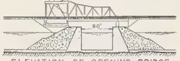
PROFILE OF ROCKFILL CROSSING, AND BRIDGE
PROFIL DU PASSAGE EN ENROCHEMENT, ET DU PONT

NOTES

TOUTES LES ÉLÉVATIONS MONTRÉES SUR CE DESSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE À PORT BORDEN

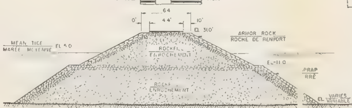
LES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS AU-DESSOUS DES DONNÉES GÉODÉSIQUES CANADIENNES

AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
MAXIMUM - ÉL 10'
MOYENNE - ÉL 5'
MINIMUM - ÉL 0'



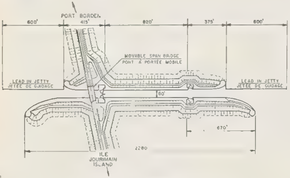
ELEVATION OF OPENING BRIDGE
ÉLÉVATION DU PONT MOBILE

SCALE / ÉCHELLE 80 0 80 FEET / PIEDS



ROCKFILL SECTION B-B
ENROCHEMENT - COUPE B-B

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



PLAN OF SHIP NAVIGATION LOCK
PLAN DE L'ÉCLUSE POUR NAVIGATION

SCALE / ÉCHELLE 300 0 300 FEET / PIEDS

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE -
MAXIMUM - EL 10'
MEAN - EL 5'
MINIMUM - EL 0'

PASSAGE DU DÉTROIT DE NORTHUMBERLAND

SOLUTION 3-B

PASSAGE PARTIEL EN ENROCHEMENT
PONT
PONT MOBILE
ROUTE À DEUX VOIES

GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS
NORTHUMBERLAND CONSULTANTS LIMITED

MARS 1964 | PLANCHE 15

NORTHUMBERLAND STRAIT CROSSING

SCHEME 3-B

PARTIAL ROCKFILL CROSSING
BRIDGE
OPENING BRIDGE
TWO LANE HIGHWAY

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS
NORTHUMBERLAND CONSULTANTS LIMITED

MARCH 1964 | PLATE 15

SCHEME 3-B - Two-Lane Highway

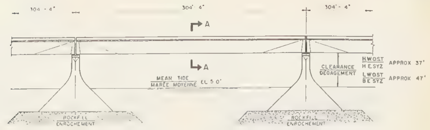
The general description which has been given for the partial rockfill causeway, bridge on prefabricated piers, and a navigation lock applies to this variation of the scheme, as shown on Plate 15 opposite.

The rockfill causeway section has a crest width of 64 feet to accommodate two 12-foot traffic lanes with 10-foot paved shoulders. The bridge section consists of a series of prefabricated concrete or steel box girders spanning approximately 300 feet. The highway on this structure consists of two 12-foot traffic lanes with 5-foot outer safety lanes, making an overall paved width of 34 feet.

ESTIMATE OF COST

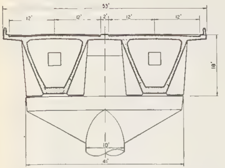
Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Rockfill Causeway	—	—	$ Sum	$ 18.004
Bridge				
Granitic Fill	C.y.	3,830,000	5.00	19.150
Piers	Each	89	228,000.00	20.292
Bridge	L.f.	26,752	550.00	14.714
Navigation Lock	—	—	Sum	8.830
Miscellaneous	—	—	Sum	1.825
Subtotal				$ 82.703
Engineering and Supervision at 5 per cent				4.297
TOTAL				$ 87.000

The estimated annual operating and maintenance cost is $465,000.



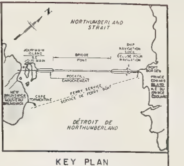
ELEVATION OF BRIDGE
ÉLÉVATION DU PONT

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



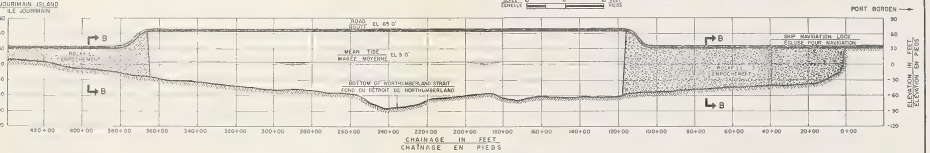
SECTION A-A - 4 LANE HIGHWAY
COUPE A-A - ROUTE À 4 VOIES

SCALE / ÉCHELLE 10 0 10 FEET / PIEDS



KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES



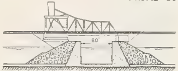
PROFILE OF ROCKFILL CROSSING, AND BRIDGE
PROFIL DU PASSAGE EN ENROCHEMENT, ET DU PONT

S

LES ÉLÉVATIONS MONTRÉES SUR CE ... SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE ... - BORDEN

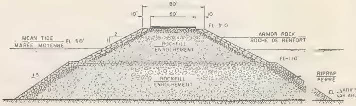
... SSES EAUX DE SYZYGIE SONT À 4.9 PIEDS ... SSOUS DES DONNÉES GÉODÉSIQUES ... NNES

... UDE EXTRÊME APPROXIMATIVE DE LA MARÉE
MAXIMUM = ÉL 10'
MOYENNE = ÉL 5'
MINIMUM = ÉL 0'



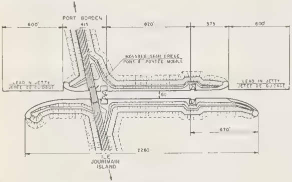
ELEVATION OF OPENING BRIDGE
ÉLÉVATION DU PONT MOBILE

SCALE / ÉCHELLE 80 0 80 FEET / PIEDS



ROCKFILL SECTION B-B
ENROCHEMENT - COUPE B-B

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



PLAN OF SHIP NAVIGATION LOCK
PLAN DE L'ÉCLUSE POUR NAVIGATION

SCALE / ÉCHELLE 300 0 300 FEET / PIEDS

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE-
MAXIMUM = EL 10'
MEAN = EL 5'
MINIMUM = EL 0'

... DU DÉTROIT DE NORTHUMBERLAND
... OLUTION 3-C
... E PARTIEL EN ENROCHEMENT
PONT
PONT MOBILE
... OUTE À QUATRE VOIES
... OUVERNEMENT DU CANADA
... TÈRE DES TRAVAUX PUBLICS
... ERLAND CONSULTANTS LIMITED
... 1964 | PLANCHE 16

NORTHUMBERLAND STRAIT CROSSING

SCHEME 3-C

PARTIAL ROCKFILL CROSSING
BRIDGE
OPENING BRIDGE
FOUR LANE HIGHWAY

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS

NORTHUMBERLAND CONSULTANTS LIMITED

MARCH 1964 | PLATE 16

SCHEME 3-C - Four-Lane Highway

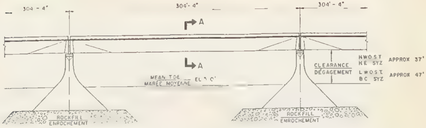
The general description which has been given for the partial rockfill causeway, bridge on prefabricated piers, and a navigation lock applies to this variation of the scheme as shown on Plate 16 opposite.

The rockfill causeway section has a crest width of 80 feet to accommodate four 12-foot traffic lanes with opposing traffic separated by a 4-foot barricaded median and having 4-foot paved outer shoulders. The bridge section consists of twin prefabricated concrete or steel box girders spanning approximately 300 feet, and providing four 12-foot traffic lanes.

ESTIMATE OF COST

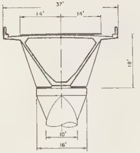
Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Rockfill Causeway	—	—	$ Sum	$ 18.642
Bridge				
Granitic Fill	C.y.	3,830,000	5.00	19.150
Piers	Each	89	228,000.00	20.292
Bridge	L.f.	26,752	950.00	25.414
Navigation Lock	—	—	Sum	8.830
Miscellaneous	—	—	Sum	1.945
Subtotal				$ 94.273
Engineering and Supervision at 5 per cent				4.727
TOTAL				$ 99.000

The estimated annual operating and maintenance cost is $485,000.



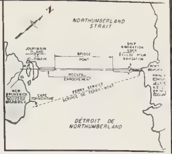
ELEVATION OF BRIDGE
ÉLÉVATION DU PONT

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



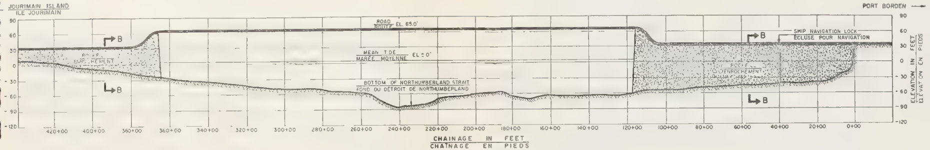
SECTION A-A
COUPE A-A

SCALE / ÉCHELLE 10 0 10 FEET / PIEDS



KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES



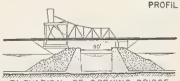
PROFILE OF ROCKFILL CROSSING, AND BRIDGE
PROFIL DU PASSAGE EN ENROCHEMENT, ET DU PONT

TES

UTES LES ÉLÉVATIONS MONTRÉES SUR CE
SSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE
ORT-BORDEN

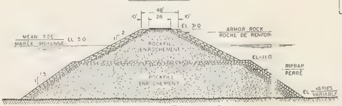
S BASSES EAUX DE SYZYGIE SONT A 4.9 PIEDS
-DESSOUS DES DONNÉES GÉODÉSIQUES
NADIENNES

LITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
MAXIMUM • EL 10
MOYENNE • EL 5'
MINIMUM • EL 0



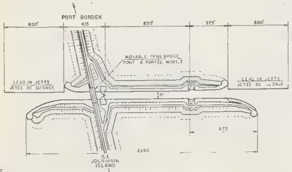
ELEVATION OF OPENING BRIDGE
ÉLÉVATION DU PONT MOBILE

SCALE / ÉCHELLE 80 0 80 FEET / PIEDS



ROCKFILL SECTION B-B
ENROCHEMENT - COUPE B-B

SCALE / ÉCHELLE 40 0 40 FEET / PIEDS



PLAN OF SHIP NAVIGATION LOCK
PLAN DE L'ÉCLUSE POUR NAVIGATION

SCALE / ÉCHELLE 300 0 300 FEET / PIEDS

NOTES

1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE -
MAXIMUM • EL 10
MEAN • EL 5'
MINIMUM • EL 0

AGE DU DÉTROIT DE NORTHUMBERLAND
SOLUTION 3-D
AGE PARTIEL EN ENROCHEMENT
PONT
PONT MOBILE
ROUTE À DEUX VOIES
DE 28' DE LARGEUR

GOUVERNEMENT DU CANADA
INISTÈRE DES TRAVAUX PUBLICS
MBERLAND CONSULTANTS LIMITED
5 1964 | PLANCHE 17

NORTHUMBERLAND STRAIT CROSSING
SCHEME 3-D
PARTIAL ROCKFILL CROSSING
BRIDGE
OPENING BRIDGE
28' WIDE TWO LANE HIGHWAY

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS
NORTHUMBERLAND CONSULTANTS LIMITE

MARCH 1964 | PLATE 17

SCHEME 3-D - Two-Lane Highway to Minimum Standards

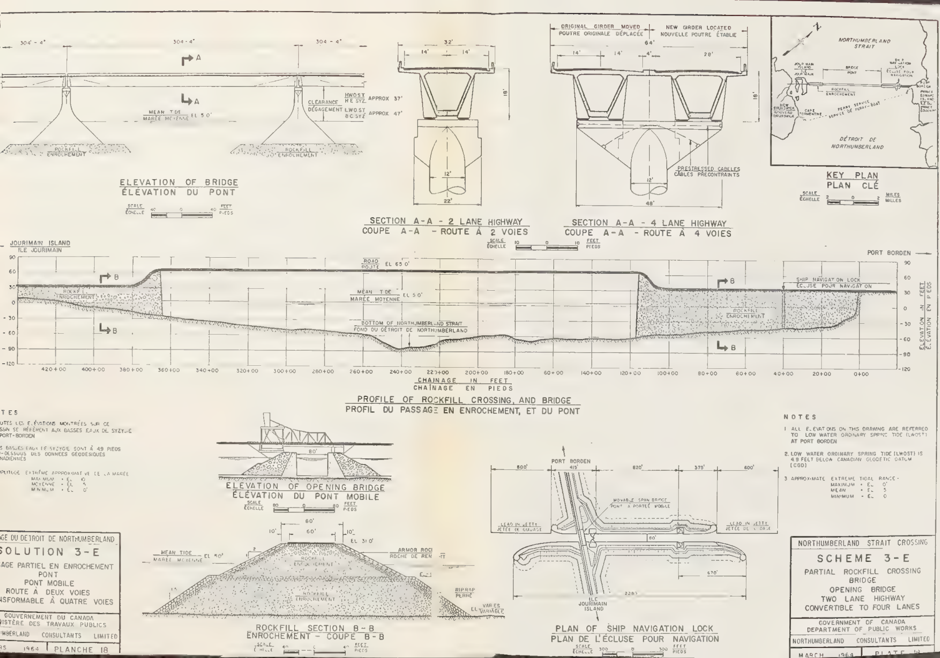
The general description which has been given for the partial rockfill causeway, bridge on prefabricated piers, and a navigation lock applies to this variation of the scheme as shown on Plate 17 opposite.

The rockfill causeway section has a crest width of 48 feet to accommodate a 28-foot highway without shoulders. The bridge section comprises a series of prefabricated concrete or steel box girders spanning approximately 300 feet. The highway on this structure consists of two 14-foot traffic lanes.

ESTIMATE OF COST

Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Rockfill Causeway	—	—	$ Sum	$ 16.534
Bridge				
Granitic Fill	C.y.	3,830,000	5.00	19.150
Piers	Each	89	228,000.00	20.292
Bridge	L.f.	26,752	500.00	13.376
Navigation Lock	—	—	Sum	8.830
Miscellaneous	—	—	Sum	1.474
Subtotal				$ 80.094
Engineering and Supervision at 5 per cent				3.906
TOTAL				$ 84.000

The estimated annual operating and maintenance cost is $465,000.



ELEVATION OF BRIDGE
ÉLÉVATION DU PONT
304' - 4"
MEAN TIDE
MARÉE MOYENNE EL 5.0'
CLEARANCE
DÉGAGEMENT
HWOST
HE SYZ
LWOST
BC SYZ
APPROX 37'
APPROX 47'
ROCKFILL
ENROCHEMENT
SCALE
ÉCHELLE
FEET
PIEDS
SECTION A-A - 2 LANE HIGHWAY
COUPE A-A - ROUTE À 2 VOIES
SECTION A-A - 4 LANE HIGHWAY
COUPE A-A - ROUTE À 4 VOIES
ORIGINAL GIRDER MOVED
POUTRE ORIGINALE DÉPLACÉE
NEW GIRDER LOCATED
NOUVELLE POUTRE ÉTABLIE
PRESTRESSED CABLES
CÂBLES PRÉCONTRAINTS
NORTHUMBERLAND STRAIT
DÉTROIT DE NORTHUMBERLAND
CAPE TORMENTINE
FERRY SERVICE
SERVICE DE FERRY-BOAT
BRIDGE
PONT
ROCKFILL
ENROCHEMENT
KEY PLAN
PLAN CLÉ
MILES
MILLES
JOURIMAIN ISLAND
ÎLE JOURIMAIN
PORT BORDEN
ROAD
ROUTE EL 65.0'
MEAN TIDE
MARÉE MOYENNE EL 5.0'
BOTTOM OF NORTHUMBERLAND STRAIT
FOND DU DÉTROIT DE NORTHUMBERLAND
SHIP NAVIGATION LOCK
ÉCLUSE POUR NAVIGATION
ELEVATION IN FEET
ÉLÉVATION EN PIEDS
CHAINAGE IN FEET
CHAÎNAGE EN PIEDS
PROFILE OF ROCKFILL CROSSING, AND BRIDGE
PROFIL DU PASSAGE EN ENROCHEMENT, ET DU PONT
NOTES
1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE - MAXIMUM + EL 10' MEAN + EL 5' MINIMUM + EL 0'
NOTES
TOUTES LES ÉLÉVATIONS MONTRÉES SUR CE DESSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE À PORT-BORDEN
LES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS AU-DESSOUS DES DONNÉES GÉODÉSIQUES CANADIENNES
AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE MAXIMUM + EL 10 MOYENNE + EL 5 MINIMUM + EL 0
ELEVATION OF OPENING BRIDGE
ÉLÉVATION DU PONT MOBILE
ROCKFILL SECTION B-B
ENROCHEMENT - COUPE B-B
ARMOR ROCK
ROCHE DE RENFORT
RIPRAP
PERRÉ
EL VARIES
VARIABLE
EL 31.0'
PLAN OF SHIP NAVIGATION LOCK
PLAN DE L'ÉCLUSE POUR NAVIGATION
MOVABLE SPAN BRIDGE
PONT À PORTÉE MOBILE
LEAD IN JETTY
JETÉE DE GUIDAGE
ÎLE JOURIMAIN ISLAND
PASSAGE DU DÉTROIT DE NORTHUMBERLAND
SOLUTION 3-E
PASSAGE PARTIEL EN ENROCHEMENT
PONT
PONT MOBILE
ROUTE À DEUX VOIES
TRANSFORMABLE À QUATRE VOIES
GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS
NORTHUMBERLAND CONSULTANTS LIMITED
MARS 1964
PLANCHE 18
NORTHUMBERLAND STRAIT CROSSING
SCHEME 3-E
PARTIAL ROCKFILL CROSSING
BRIDGE
OPENING BRIDGE
TWO LANE HIGHWAY
CONVERTIBLE TO FOUR LANES
GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS
NORTHUMBERLAND CONSULTANTS LIMITED
MARCH 1964
PLATE 18

SCHEME 3-E - Two-Lane Highway Convertible to Four Lanes

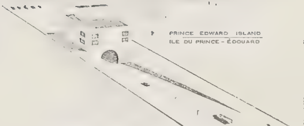
The general description which has been given for the partial rockfill causeway, bridge on prefabricated piers, and a navigation lock applies to this variation of the scheme as shown on Plate 18 opposite.

The rockfill causeway section has a crest width of 80 feet which can ultimately accommodate four 12-foot traffic lanes with opposing traffic separated by a 4-foot barricaded median, and having 4-foot paved outer shoulders. The bridge section consists of a series of prefabricated concrete or steel box girders spanning approximately 300 feet. The highway on this structure consists of two 14-foot traffic lanes. The piers are designed so that the pier caps can be extended on each side to allow a second box girder to be placed alongside the first. The original box girder will be jacked to one side to provide the necessary room on the extended pier cap.

ESTIMATE OF COST

Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Rockfill Causeway	—	—	$ Sum	$ 18.104.
Bridge				
Granitic Fill	C.y.	3,830,000	5.00	19.150
Piers	Each	89	250,000.00	22.250
Bridge	L.f.	26,752	500.00	13.376
Navigation Lock	—	—	Sum	8.830
Miscellaneous	—	—	Sum	1.954
Subtotal				$ 83.664
Engineering and Supervision at 5 per cent				4.336
TOTAL for Two-Lane Highway				$ 88.000
Conversion Cost (including engineering and supervision)				17.000
TOTAL for Four-Lane Highway				$105.000

The estimated annual operating maintenance cost with the two-lane open causeway is $465,000.



UNDERGROUND TUNNEL
TUNNEL SOUTERRAIN

PLATE
PLANCHE 19

UNDERGROUND TUNNEL

Description

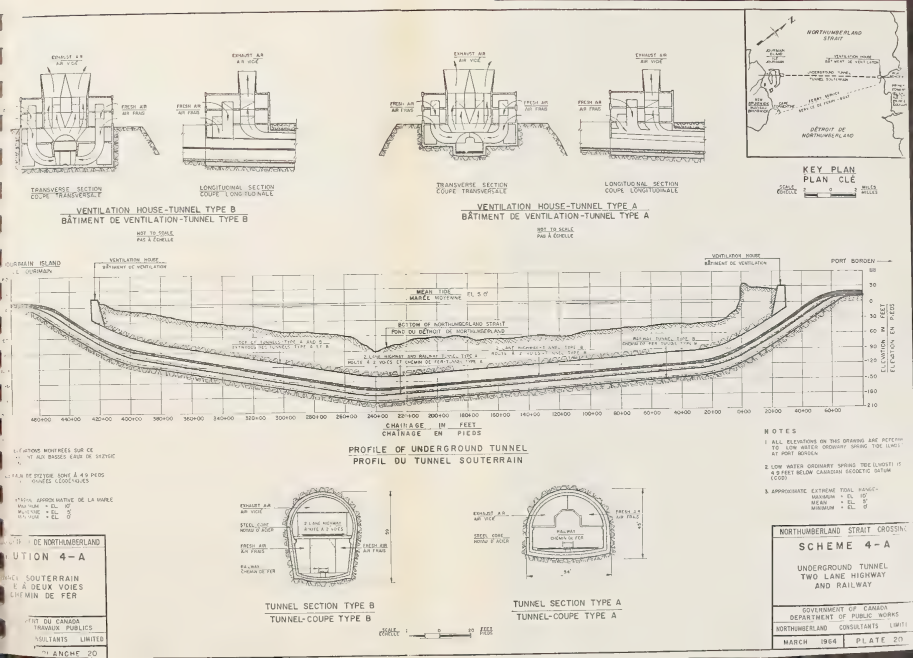
This general scheme, as shown on Plate 19 opposite, consists of a tunnel driven under the Strait between Jourimain, New Brunswick, and Port Borden, Prince Edward Island.

In order to obtain sufficient cover over the tunnel, and satisfactory gradients for rail traffic, the length of the combined road and rail tunnel is approximately nine miles. Highway traffic, however, can negotiate steeper gradients so that the highway tunnel schemes are somewhat shorter. Both single deck and double deck designs have been considered and are discussed.

Advantages and Disadvantages

The obvious advantage of constructing a full underground tunnel is that it eliminates all problems connected with changes in tidal regime in the Strait. It is not subject to closure or damage due to storms or ice, and it presents no obstacle to navigation in the Strait. Serious problems arise, however, in the design, construction and operation of the tunnel.

The lack of a comparable precedent raises technical difficulties regarding the feasibility of ventilating a tunnel of this length. In the only other tunnel, of comparable length in the world, the Mont Blanc tunnel, the capacity of the tunnel is limited by the ventilation system to 450 cars per hour. This is less than one half of the practical capacity of a comparable two-lane highway above ground level. The high porosity of the rock formations likely to be found under the Strait suggest that a severe problem of leakage control will be encountered, and that construction progress will therefore be slow. Extensive and expensive ground exploration will be necessary to decide the feasibility of excavating a tunnel. In addition to the technical difficulties already noted, there is the natural reluctance of many humans to confinement for long distances in an underwater tunnel.


NORTHUMBERLAND STRAIT
VENTILATION HOUSE
BÂTIMENT DE VENTILATION
UNDERGROUND TUNNEL
TUNNEL SOUTERRAIN
FERRY SERVICE
SERVICE DE FERRY - BOAT
CAPE TORMENTINE
NEW BRUNSWICK
DÉTROIT DE NORTHUMBERLAND
KEY PLAN
PLAN CLÉ
SCALE ÉCHELLE 2 0 2 MILES MILLES
EXHAUST AIR
AIR VICIÉ
FRESH AIR
AIR FRAIS
TRANSVERSE SECTION
COUPE TRANSVERSALE
LONGITUDINAL SECTION
COUPE LONGITUDINALE
VENTILATION HOUSE-TUNNEL TYPE B
BÂTIMENT DE VENTILATION-TUNNEL TYPE B
NOT TO SCALE
PAS À ÉCHELLE
VENTILATION HOUSE-TUNNEL TYPE A
BÂTIMENT DE VENTILATION-TUNNEL TYPE A
NOT TO SCALE
PAS À ÉCHELLE
JOURIMAIN ISLAND
PORT BORDEN
MEAN TIDE
MARÉE MOYENNE EL 5.0'
BOTTOM OF NORTHUMBERLAND STRAIT
FOND DU DÉTROIT DE NORTHUMBERLAND
2 LANE HIGHWAY AND RAILWAY TUNNEL TYPE A
ROUTE À 2 VOIES ET CHEMIN DE FER-TUNNEL TYPE A
RAILWAY TUNNEL TYPE B
CHEMIN DE FER TUNNEL TYPE B
30 0 -30 -60 -90 -120 -150 -180 -210
ELEVATION IN FEET
ÉLÉVATION EN PIEDS
460+00 440+00 420+00 400+00 380+00 360+00 340+00 320+00 300+00 280+00 260+00 240+00 220+00 200+00 180+00 160+00 140+00 120+00 100+00 80+00 60+00 40+00 20+00 0+00 20+00 40+00 60+00
CHAINAGE IN FEET
CHAÎNAGE EN PIEDS
PROFILE OF UNDERGROUND TUNNEL
PROFIL DU TUNNEL SOUTERRAIN
NOTES
1 ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2 LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3 APPROXIMATE EXTREME TIDAL RANGE-
MAXIMUM = EL. 10'
MEAN = EL. 5'
MINIMUM = EL. 0'
EXHAUST AIR
AIR VICIÉ
STEEL CORE
NOYAU D'ACIER
2 LANE HIGHWAY
ROUTE À 2 VOIES
FRESH AIR
AIR FRAIS
RAILWAY
CHEMIN DE FER
59'
45'
54'
TUNNEL SECTION TYPE B
TUNNEL-COUPE TYPE B
TUNNEL SECTION TYPE A
TUNNEL-COUPE TYPE A
SCALE ÉCHELLE 0 20 FEET PIEDS
NORTHUMBERLAND STRAIT CROSSING
SCHEME 4-A
UNDERGROUND TUNNEL
TWO LANE HIGHWAY
AND RAILWAY
GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS
NORTHUMBERLAND CONSULTANTS LIMITED
MARCH 1964
PLATE 20
DE NORTHUMBERLAND
SOUTERRAIN
CHEMIN DE FER
TRAVAUX PUBLICS
LIMITED
PLANCHE 20

SCHEME 4-A - Two-Lane Highway and Railway

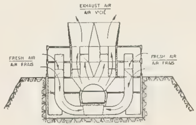
The general description which has been given for the underground tunnel applies to this variation of the scheme as shown on Plate 20 opposite.

In order to obtain sufficient cover over the tunnel and conform to railway gradients, the length of the tunnel exceeds 46,000 feet. Two possible tunnel sections, Type A and Type B, are considered. In Type A, the railway is carried at the same elevation as the highway, which enables the railway lane to be used as an emergency lane when no train is in the tunnel. Tunnel Type B utilizes two levels with the highway on the upper level and a single track railway on the lower level. The Type A section gives a lower tunnel height so that the railway can be maintained at a higher level than is possible with the Type B section. Consequently, the total length of Type A tunnel is approximately 3,000 feet shorter than the Type B tunnel.

ESTIMATE OF COST

Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Type A				
Tunnel Excavation	C.y.	3,550,000	$ 12.00	$ 42.600
Concrete Lining & Steel Supports	—	—	Sum	55.468
Ventilation and Electrical	—	—	Sum	22.500
Miscellaneous	—	—	Sum	20.335
Subtotal				$140.903
Engineering and Supervision at 5 per cent				7.097
TOTAL				$148.000
Type B				
Tunnel Excavation	C.y.	3,930,000	$12.00	$ 47.160
Concrete Lining & Steel Supports	—	—	Sum	53.492
Ventilation and Electrical	—	—	Sum	22.500
Miscellaneous	—	—	Sum	27.020
Subtotal				$150.172
Engineering and Supervision at 5 per cent				7.828
TOTAL				$158.000

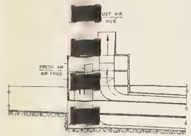
The estimated annual operating and maintenance cost is $1,050,000 with the Type A tunnel, and $1,010,000 with the Type B tunnel.



TRANSVERSE SECTION
COUPE TRANSVERSALE

VENTILATION HOUSE-TUNNEL TYPE B
BÂTIMENT DE VENTILATION-TUNNEL TYPE B

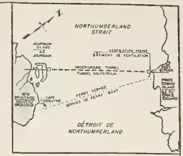
NOT TO SCALE
PAS À ÉCHELLE



LON SECTION
COU TUDINALE

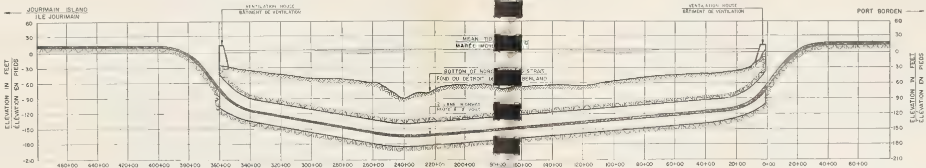
VENTILATION -TUNNEL TYPE A
BÂT MENT DE V ION-TUNNEL TYPE A

NOT TO SCALE
PAS À ÉCHELLE



KEY PLAN
PLAN CLÉ

SCALE / ÉCHELLE 2 0 2 MILES / MILLES



CHAINAGE IN
CHAÎNAGE EN

PROFILE OF UNDERGROUND TUNNEL
PROFIL DU TUNNEL RRAIN

NOTES

1 TOUTES LES ÉLÉVATIONS MONTRÉES SUR CE DESSIN SE RÉFÉRENT AUX BASSES EAUX DE SYZYGIE À PORT-BORDEN

2 LES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS AU-DESSOUS DES DONNÉES GÉODÉSIQUES CANADIENNES

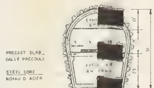
3 AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
MAXIMUM = EL 10'
MOYENNE = EL 5'
MINIMUM = EL 0'

NOTES

1 ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN

2 LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)

3 APPROXIMATE EXTREME TIDAL RANGE-
MAXIMUM = EL 10'
MEAN = EL 5'
MINIMUM = EL 0'



TUNNEL SECTION TYPE C
TUNNEL-COU PE C

20 FEET / PIEDS

SSAGE DU DÉTROIT DE NORTHUMBERLAND

SOLUTION 4-B

TUNNEL SOUTERRAIN
ROUTE À DEUX VOIES

GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS

THUMBERLAND CONSULTANTS LIMITED

IARS 1964 | PLANCHE 21

NORTHUMBERLAND STRAIT CROSSING

SCHEME 4-B

UNDERGROUND TUNNEL
TWO LANE HIGHWAY

GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS

NORTHUMBERLAND CONSULTANTS LIMITED

MARCH 1964 | PLATE 21

SCHEME 4-B - Two-Lane Highway

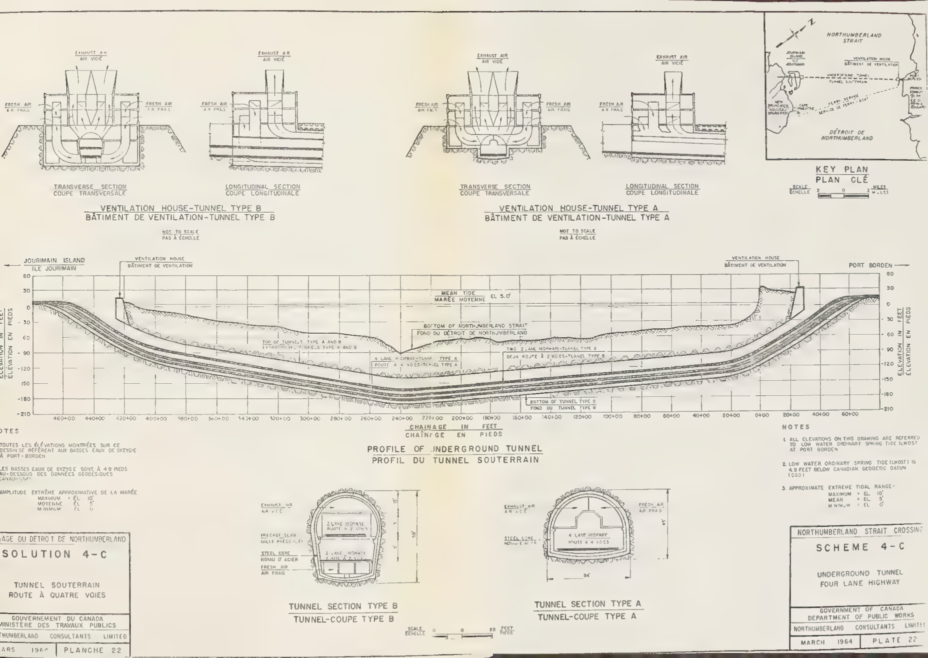
The general description which has been given for the underground tunnel applies to this variation of the scheme as shown on Plate 21 opposite.

The elimination of the railway permits the use of increased gradients so that the length of tunnel may be reduced to approximately 36,000 feet. A third tunnel section, Type C, is proposed for this scheme, in which the highway would be carried on an upper level with ventilation ducts both above and below. It is not possible to convert the tunnel to a four-lane facility but provision has been made for an emergency or breakdown lane to permit the rapid removal of disabled vehicles with little or no interference to the free flow of traffic.

ESTIMATE OF COST

Item	Unit	Quantity	Unit Cost	Cost in Millions of Dollars
Tunnel Excavation	C.y.	2,620,000	$ 12.00	$ 31.440
Concrete Lining & Steel Supports	—	—	Sum	38.520
Ventilation and Electrical	—	—	Sum	18.000
Miscellaneous	—	—	Sum	14.755
Subtotal				$102.715
Engineering and Supervision at 5 per cent				5.285
TOTAL				$108.000

The estimated annual operating and maintenance cost is $850,000.


EXHAUST AIR
AIR VICIÉ
FRESH AIR
AIR FRAIS
TRANSVERSE SECTION
COUPE TRANSVERSALE
LONGITUDINAL SECTION
COUPE LONGITUDINALE
VENTILATION HOUSE-TUNNEL TYPE B
BÂTIMENT DE VENTILATION-TUNNEL TYPE B
NOT TO SCALE
PAS À ÉCHELLE
VENTILATION HOUSE-TUNNEL TYPE A
BÂTIMENT DE VENTILATION-TUNNEL TYPE A
NOT TO SCALE
PAS À ÉCHELLE
NORTHUMBERLAND STRAIT
JOURIMAIN ISLAND
ILE JOURIMAIN
VENTILATION HOUSE
BÂTIMENT DE VENTILATION
UNDERGROUND TUNNEL
TUNNEL SOUTERRAIN
FERRY SERVICE
SERVICE DE FERRY-BOAT
CAPE TORMENTINE
NEW BRUNSWICK
NOUVEAU BRUNSWICK
PRINCE EDWARD ISLAND
DÉTROIT DE NORTHUMBERLAND
KEY PLAN
PLAN CLÉ
SCALE
ÉCHELLE
2 0 2 MILES
JOURIMAIN ISLAND
ILE JOURIMAIN
VENTILATION HOUSE
BÂTIMENT DE VENTILATION
PORT BORDEN
MEAN TIDE
MARÉE MOYENNE EL 5.0'
BOTTOM OF NORTHUMBERLAND STRAIT
FOND DU DÉTROIT DE NORTHUMBERLAND
TOP OF TUNNELS TYPE A AND B
4 LANE HIGHWAY-TUNNEL TYPE A
ROUTE À 4 VOIES-TUNNEL TYPE A
TWO 2 LANE HIGHWAYS-TUNNEL TYPE B
DEUX ROUTE À 2 VOIES-TUNNEL TYPE B
BOTTOM OF TUNNEL TYPE B
FOND DU TUNNEL TYPE B
ELEVATION IN FEET
ÉLÉVATION EN PIEDS
60 30 0 -30 -60 -90 -120 -150 -180 -210
460+00 440+00 420+00 400+00 380+00 360+00 340+00 320+00 300+00 280+00 260+00 240+00 220+00 200+00 180+00 160+00 140+00 120+00 100+00 80+00 60+00 40+00 20+00 0+00 20+00 40+00 60+00
CHAINAGE IN FEET
CHAÎNAGE EN PIEDS
PROFILE OF UNDERGROUND TUNNEL
PROFIL DU TUNNEL SOUTERRAIN
NOTES
TOUTES LES ÉLÉVATIONS MONTRÉES SUR CE DESSIN SE RÉFÈRENT AUX BASSES EAUX DE SYZYGIE À PORT-BORDEN
LES BASSES EAUX DE SYZYGIE SONT À 4.9 PIEDS AU-DESSOUS DES DONNÉES GÉODÉSIQUES CANADIENNES
AMPLITUDE EXTRÊME APPROXIMATIVE DE LA MARÉE
MAXIMUM = ÉL 10'
MOYENNE = ÉL 5'
MINIMUM = ÉL 0'
NOTES
1. ALL ELEVATIONS ON THIS DRAWING ARE REFERRED TO LOW WATER ORDINARY SPRING TIDE (LWOST) AT PORT BORDEN
2. LOW WATER ORDINARY SPRING TIDE (LWOST) IS 4.9 FEET BELOW CANADIAN GEODETIC DATUM (CGD)
3. APPROXIMATE EXTREME TIDAL RANGE-
MAXIMUM = EL 10'
MEAN = EL 5'
MINIMUM = EL 0'
EXHAUST AIR
AIR VICIÉ
2 LANE HIGHWAY
ROUTE À 2 VOIES
PRECAST SLAB
DALLE PRÉCOULÉE
STEEL CORE
NOYAU D'ACIER
FRESH AIR
AIR FRAIS
TUNNEL SECTION TYPE B
TUNNEL-COUPE TYPE B
EXHAUST AIR
AIR VICIÉ
FRESH AIR
AIR FRAIS
STEEL CORE
NOYAU D'ACIER
4 LANE HIGHWAY
ROUTE À 4 VOIES
54'
TUNNEL SECTION TYPE A
TUNNEL-COUPE TYPE A
SCALE
ÉCHELLE
0 20 FEET
PIEDS
PASSAGE DU DÉTROIT DE NORTHUMBERLAND
SOLUTION 4-C
TUNNEL SOUTERRAIN
ROUTE À QUATRE VOIES
GOUVERNEMENT DU CANADA
MINISTÈRE DES TRAVAUX PUBLICS
NORTHUMBERLAND CONSULTANTS LIMITED
MARS 1964
PLANCHE 22
NORTHUMBERLAND STRAIT CROSSING
SCHEME 4-C
UNDERGROUND TUNNEL
FOUR LANE HIGHWAY
GOVERNMENT OF CANADA
DEPARTMENT OF PUBLIC WORKS
NORTHUMBERLAND CONSULTANTS LIMITED
MARCH 1964
PLATE 22

SCHEME 4-C - Four-Lane Highway

The general description which has been given for the underground tunnel applies to this variation of the scheme as shown on Plate 22 opposite.

It is considered extremely difficult and possibly not technically feasible to ventilate a four-lane tunnel of this length to permit utilization of its full capacity. To our knowledge no similar structure has ever been constructed and therefore reliable costs are not available. The ventilation problem requires a careful examination and, due to the extremely high cost anticipated for this type of facility, it is considered that a full study is not justified at this time.

Conversion of Scheme 4-A to a four-lane facility will result in a tentative minimum cost of some $170 million for the Type A tunnel, and some $180 million for the Type B tunnel.